THE MULCHING OF VEGETABLES

by

PATRICIA ROWE-DUTTON

Technical Communication No. 24
Commonwealth Bureau of Horticulture and Plantation Crops
East Malling, Maidstone, Kent

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Commonwealth Bureau of Horticulture and Plantation Crops

With Foreword by

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PREFACE

This is the second of two or more Technical Communications to be issued by the Commonwealth Bureaux of Soils and of Horticulture and Plantation Crops.

The first, which concerned the effects of mulching on soil properties and stubble-mulch farming, was issued in 1955 as T.C.49 of the Bureau of Soil Science.*

The present work has been compiled by Miss Patricia Rowe-Dutton of the Bureau of Horticulture and revised in accordance with criticism from J. J. Woods, Superintendent, Dominion Experimental Farm, Saanichton, B.C., who has also provided a foreword.

If sufficient interest is evinced it may be possible to follow this up with similar publications on the mulching of fruit crops, of tropical crops and of ornamentals. A decision on this point depends partly on the expressed wishes of our correspondents, partly on the reception given to the present work and partly on the availability of staff to carry out the long task of collection and compilation.

* Then so named.

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First we thank all our official and unofficial correspondents who encouraged the project and sent us useful information.

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Finally, we very greatly appreciate the action of Mr. J. J. Woods of Saanichton, B.C., in reading through and most helpfully criticizing the draft, in providing a foreword and in lending us attractive photographs to enliven what is, of necessity, a not very exciting scene.

D. Akenhead.

East Malling
May 1957

FOREWORD

The application of a covering layer of material, a mulch, for agricultural crops is a method of growing certain plants that has been a research problem for well over half a century. Early papers on this subject were published during the '80's and '90's, but the late 1920's and the early 1930's were periods of considerable concentration owing largely to the introduction of paper mulch. One of the most recently introduced materials is aluminium foil and this, or a more economically priced material, might well give an impetus to mulching comparable to that given by paper mulch thirty years ago.

The outstanding effect and virtue of mulches has undoubtedly been their conservation of moisture. Possibly a certain amount of bias in this direction has accrued from the fact that many research workers were at one time led to believe that dust mulching was an effective and direct means of conserving soil moisture. That a covering layer of material conserves moisture there can be no doubt, but the secondary role of mulch—its effect on soil temperature—has been much less emphasized than its moisture effect. As moisture is more readily controlled by irrigation than is heat by artificial application, one can look forward to the time when studies on heat and reflected light will be given more consideration than has been the case in the past. Very little research has been undertaken on the effect of continuous mulching on soil organic matter and permanent soil fertility. Mulch materials can be classed as tools for the research worker that he may better study temperature, light, root development and plant maturity in different local environments.

The practical value of mulching is determined by the cost of material, the labour involved in application, savings made in weed control and profit resulting from the overall operation. Choice must therefore fall on those kinds which are readily and economically available. Their use offers to a considerable extent a different method of growing crops and prejudice for established methods may for a time influence the amount of mulching done.

Apart from the commercial aspect of mulches for vegetable crops, there is the important phase of the home vegetable garden. The home gardener may well contemplate a permanent mulch with such material as sawdust applied at a depth of three inches and each year sow seed on the interphase of soil and sawdust. The labour of digging the soil need not be undertaken though there is some evidence that compaction under sawdust mulch is an inherent property of the soil influenced by the percentage of

the clay fraction. Fertilizer can be applied at such time that rain or irrigation will wash it through to the soil. Under such a system of culture, root crops are more readily pulled or dug and potato crops can be dug by hand as tubers form at the interphase of soil and mulch. Feeder roots only penetrate the soil. Under the same conditions it has been observed that the troublesome weed, *Portulaca oleracea*, has been completely smothered except where the sawdust mulch becomes thinner than suggested. In areas where the garden slug, *Arion circumscriptus*, is troublesome, it has been observed that a sawdust mulch offers a good measure of control. Mulch culture in the vegetable garden, while it may not control all weed growth or eliminate all necessity for watering, offers numerous worthwhile advantages, even though it may delay the maturity of some heat-loving crops, such as tomatoes.

The author of this publication has not attempted to present any final methods or clear cut advantages of a mulching practice. Interpreting the results of more than three hundred publications representing papers in different languages from different continents and dealing with a great variety of crops has been a most ambitious task. In presenting the often contradictory results of the papers reviewed rather than attempting to present practices which growers could follow without hesitation has resulted in a publication which research workers may find of greater value than the commercial grower, but for the latter also the information and guidance is there if he will but seek it. That the task has been well done will be immediately appreciated by all those who are fortunate enough to read what has been written.

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CHAPTER 1

INTRODUCTION

Definition of Mulching

Probably the most satisfactory definition of the term mulching, from a horticultural point of view, is " the application of a covering layer of material to the soil surface ". This intentionally excludes the system known as dust mulching, i.e. the formation of a loose surface layer of soil by means of shallow cultivation. There has been a long and heated controversy over the value of dust mulching as a means of conserving moisture, but it is now considered that its chief value lies in the destruction of weeds, with a consequent reduction in loss of water through transpiration. Since this system does not involve the " application " of any material to the soil surface, it cannot strictly be considered as mulching.

Any type of material may in theory be used as a mulch, but naturally some are more suitable for horticultural purposes than others. Even in practice there is an amazing variety in the materials employed. The range extends from natural substances such as plant residues, peat, manure, stones, etc. to manufactured materials including asphalt paper, glass wool, aluminium foil, bituminous emulsion and polyethylene plastic [see Fig. 9]. Commercial choice of material will depend mainly on availability, cost and efficiency for the purposes listed below.

Purposes of Mulching

In commercial gardening the purpose of any cultural operation is to increase yields, earliness or quality of the crops by modifying environmental conditions. Innumerable claims have been made by growers and scientists alike that some or all of these benefits can be obtained as a result of mulching, while many other workers have reported decreased yields or other undesirable effects. It has been well established that the crop environment can be modified, for good or ill, in a great number of ways by the use of a mulch. In commercial practice, however, there are four primary purposes for which it is used in an attempt to improve growing conditions, namely to conserve moisture, to suppress weeds, to regulate soil temperatures and to afford winter protection.

Moisture conservation

It has repeatedly been found that, by reducing evaporation, mulches will help to conserve moisture in the soil and maintain a

more uniform supply. Harris and Yao (1923) showed that straw was very much more effective in conserving moisture than manure, while hay, grass and wood shavings were intermediate. They conclude that an efficient mulch must consist of material which does not absorb or retain moisture readily and which forms practically no capillary system in itself. The benefit will clearly be greater if it is applied when the soil is still wet than when there is little water to conserve. Mulches also help to keep moisture in the soil by suppressing weed growth and thus reducing loss through transpiration.

In addition to conserving moisture already in the soil, some mulches increase the penetration of rain or irrigation water and reduce run-off. They do this by breaking the force of the water droplets and so preventing compaction of the soil, and by protecting the soil from exposure to alternate rain and sun which may cause crusting. Other materials, however, such as dry peat, may hinder water penetration because they tend to absorb and hold the rain before it ever reaches the soil, only to release it again to the air by evaporation. Penetration may also be impeded by certain solid artificial mulches such as asphalt paper and aluminium foil, as some of the rain water will collect in hollows on the uneven surface and be lost by evaporation. Such mulches are most effective in increasing soil moisture when used on soils well supplied with ground water rather than on those mainly dependent on rain or irrigation water.

It must be borne in mind that conservation of water is not always of benefit to crops. On low-lying, badly drained sites or in very wet seasons mulched soils may become waterlogged and aeration restricted. Moreover certain crops such as melons need relatively dry conditions for proper ripening. In many parts of the world, however, lack of moisture is a limiting factor to plant growth, and in such areas suitable mulching may be expected not only to increase crop yields but to save irrigation water, to reduce the incidence of certain physiological disorders such as blossom end rot and, on seedbeds, to ensure more even germination.

Weed control

Probably the most outstanding advantage of mulching, next to water conservation, is the suppression of annual weeds and the consequent saving of labour in cultivation. Where mulch material is available cheaply and time or labour is scarce, weed control may be the primary commercial reason for applying mulches, and in home gardens where time is often a more important consideration than expense they are quite commonly used for this purpose, especially in the United States. Effective weed control depends very much on the correct choice and use of mulch material. Some materials, such as fresh manure, cereal straw or hay cut when seeding, may even increase the weed problem by introducing weed seeds. Few mulches will suppress certain persistent perennials such

as Canada thistle, and the ground should be cleared of these before application. Couch grass, on the other hand, tends to be shallow rooted under mulch and can be relatively easily pulled. The exclusion of light by the mulch cover will smother most annual weeds, provided it is applied to an adequate depth, and any wind-blown seeds that germinate on it can be pulled out easily.

For adequate suppression of annual weeds, not less than 10 tons of straw per acre are required, giving a layer 8-10 in. deep when freshly applied and about 4 in. deep when settled (Bushnell and Weaver, 1930). It has been claimed that a 1 in. layer of sawdust will suppress broad leaf weeds, especially the later crop after the first hoeing (Judkins, 1953), but for good control of annual weeds a depth of 2 in. is usually recommended (Agassiz, B.C., 1954 ; Webster *et al.*, 1954. See Fig. 3) ; even this depth does not suppress chickweed, grasses or persistent perennials. Aluminium foil, being a solid material, gives good weed control (Tiedjens, 1950). Perforated paper has generally been found unsatisfactory, but non-perforated paper will suppress weeds so long as it remains intact. Where the ground is not completely covered, the weeds tend to grow more vigorously between the paper strips (Werth, 1930). A new method of using a mulch of wet pulp made from shredded waste paper appears to prevent weed growth very satisfactorily as the mulch hardens on drying (Hamner and Rai, 1954, 1955). A bituminous emulsion which may be sprayed over the whole soil surface as a pre-germination mulch is quite ineffective as it can be penetrated by weeds as well as by crop plants (Banasevič, 1941).

Temperature regulation

It has generally been found that under organic mulches such as straw and sawdust soil temperatures are lower during the day and slightly higher at night than those of bare soil ; and that the daily range of temperature is very much narrower as a result of insulation. In practice this reduction of soil temperature is of primary importance in tropical and sub-tropical countries, and in the production of certain temperate crops in warm climates. Potatoes are a notable example, as in districts such as the southern and central States of America summer temperatures of exposed soil often exceed the optimum for tuber production. Root production is said to be favoured by a large temperature difference between soil and air (Musso, 1932), and for this reason loose, organic mulches may also be of special benefit in the production of root crops. The cooler soil conditions, however, may delay the time of harvest, and if the mulches are applied too early in the season before the ground has warmed up they may also retard nitrification and reduce growth and yields.

Dark coloured mulches, such as asphalt paper, black poly-ethylene, bituminous emulsion or soot, absorb the sun's rays and, in contrast to the light organic mulches, tend to increase the soil

temperature especially during sunny periods. Measurements of temperature differences between paper-mulched and bare soils at different times of the day and year have varied considerably. Black paper, however, has often been used successfully to make conditions more favourable for heat-loving crops and to increase earliness ; it has also made it possible to extend the northern limit of cultivation for some tender crops.

Winter protection

This appears to have been one of the most common uses of mulching in Great Britain in early times. When labour was cheap protective mulches used to be laid over autumn-sown vegetables such as peas and beans during severe frosts and removed during mild weather. Nowadays mulching as a protection against frost is used mainly on shrubs, herbaceous perennials and strawberries ; in the vegetable garden it is limited almost entirely to the perennial crops such as asparagus and globe artichokes. The old idea that winter mulch should be used as a blanket to keep the plants warm has now generally been rejected in favour of the theory that it should be applied after the ground has frozen to prevent alternate freezing and thawing which may result in heaving and tearing of plant roots.

Other purposes

Under certain special conditions mulches may be used expressly for such purposes as controlling erosion, correcting the chemical balance of the soil (notably saline or highly manganiferous soils), or reducing damage done by pests and diseases (nematodes, soil-borne fungi or seed potato viruses). Moreover, certain light-reflecting mulches have recently been used experimentally to produce a stronger radiation and shorter wave length of light which, it is thought, may increase the rate of assimilation (Száva-Kováts, 1948 ; Weger, 1950a and b, 1951a and b, 1952).

Apart from these major results, mulches may produce secondary effects such as improvement of soil structure, increase in micro-activity and earthworm populations, better utilization of nutrients, more extensive root systems, less damage to the roots by cultivation, etc. Though not perhaps in themselves justifying the expense of mulching, such effects may nevertheless be of considerable benefit to the crop or soil.

Problems of Mulching

Whether any of the desired effects mentioned above are, in fact, achieved by mulching must depend on local conditions of soil and climate, the type of mulch used and the way in which it is applied. Moreover, many of the effects are interdependent, so it is not possible for the grower to consider them in isolation. It is

therefore not surprising that one of the main reasons why mulching has sometimes given unsatisfactory results is that it has been applied under the wrong conditions or in the wrong way. For instance, heat-loving crops cannot be expected to mature properly under straw mulch in a short cool summer even though they may benefit from the better water supply ; and the use of sawdust mulch without additional fertilizer may result in crop failure due to nitrogen deficiency. Such failures are by no means entirely the fault of the grower. Experimental results have been so varied and often conflicting, advice has often been based on empirical results, and popular articles on the subject have been poured out in such profusion that the practical man cannot be expected to sort out the grain from the chaff or to piece together all the factors in a highly complex system. Moreover a survey of the literature shows that many problems still remain unsolved and that there is a real need for fundamental and coordinated research.

Another factor which may be responsible for some disappointing results is the unpredictability of the weather. A grower may realize that on his soil a mulch would be beneficial in a dry season but detrimental in a wet one ; unless he is a reliable weather prophet, however, he must take a chance. Or he may very properly delay mulching until the soil has warmed up in the spring, only to find when the time comes that a prolonged drought has set in and the soil is already too dry for mulch to be of any great benefit.

Even if a grower does obtain higher or earlier yields or better quality in his crops as a result of mulching, he may still find that the practice is uneconomic. The cost of mulch material and the labour involved in laying it may exceed the increase in returns. It is true that the saving in tillage and weed control operations can be set against the cost of mulching. So, in irrigated areas, can the saving in water and number of applications. Estimates of the relative costs of these operations have varied greatly and must depend to a large extent on local conditions. The deciding factor will probably be cost of mulch material. There is fairly general agreement that mulching will not be economic unless mulch material is available cheaply or as a local waste product. This fact helps to account for the very varied local practices such as the extensive use of sawdust in the lumbering regions of British Columbia and Alabama, of straw in grain-growing districts, and of grass in the tropics. Fortunately the common organic mulch materials do not vary very greatly in their effect on crops, as shown by Isenberg and Odland (1950) using sawdust, leaves, grass clippings, straw, corn fodder and manure. So the grower is generally justified in using the most convenient and cheapest material available. Manufactured mulch materials, however, are almost always expensive to buy, although their durability must be considered in relation to the initial cost. Paper mulch, which had such a vogue in the inter-war period, never became established commercially because it was not

only expensive to buy but was insufficiently durable and extremely laborious to lay.

In highly intensive production, where land is limited and labour cheap, mulching may be unprofitable. In Hong Kong, for instance, fields are usually covered by 7-10 crops a year and inter-cropping is common, so that the ground is quickly covered by the plants themselves. Labour for weed control and watering is plentiful and mulch material is expensive, and as a result mulches are only applied to certain special crops (Blackie, 1955).

Scope of this Technical Communication

In the following chapters an attempt has been made to review the world literature on the mulching of vegetable crops and, where possible, to draw some general conclusions from the results reported. The vast volume of work on the subject has produced many conflicting or unexplained results and a diversity of opinions. Much critical work clearly remains to be done. It is hoped that this review may help to indicate some of the points that require attention.

While endeavouring not to underestimate the complexity of the problem and the inter-relationship of the many effects of mulching, stress has been laid as much as possible on practical aspects and on any general principles or trends of horticultural significance that have emerged. This has been done in order to put the problem into some perspective and thus to enable growers to adapt the practice of mulching most satisfactorily to their own local conditions.

The effects of mulching on soil conditions have already been dealt with in a recent Technical Communication published by the Soil Science Bureau (Jacks *et al.*, 1955). Such effects are here considered as briefly as possible and only in so far as is necessary for an interpretation of results.

CHAPTER 2

ASPARAGUS

With certain perennial vegetables, notably asparagus and globe artichokes, some form of mulching appears to be a fairly widespread and standard practice, in contrast to the more localized or experimental mulching that one finds with the annual vegetables. The main reason for this lies in the need for frost protection during winter, a problem which seldom arises with annual crops. Surprisingly little experimental work has been done on the mulching of perennial vegetables ; possibly it is felt that where a traditional custom has proved satisfactory there is no need for further trial.

Seedbeeds

Although asparagus seedbeds are, or have been, quite frequently mulched, the reasons for this and the methods used vary, depending on local conditions. In England winter mulching used to be recommended as a protection against frost. The 18th-century gardener Philip Miller (1759) wrote : " toward the latter End of October, when the Haulm is quite withered, you may spread a little roten Dung over the Surface of the Ground, about an Inch thick, which will preserve the young Buds from being hurt with the Frosts, etc." Loudon (1835) gives the same advice, and adds that the mulch should remain on until March or April when the seedlings are transplanted. This well-established old practice seems now to be considered unnecessary in England, for no mention is made of it in recent literature. In the United States, however, a light cover of straw is recommended if the seedlings are to be left in the ground over winter, not so much to prevent frost damage as to protect against alternate freezing and thawing which may result in heaving of the crowns (Thompson, 1939).

In the Formby district of Lancashire, where asparagus is grown on the reclaimed sand-dunes, seedbed mulching is sometimes resorted to to prevent the seedlings and young crowns from being blown away by the wind or buried by drifting sand. The usual method of protection is to spade in rows of star grass to form vertical barriers, but where star grass is scarce a thin mulch of pine needles collected from the nearby pine woods is scattered over the beds (Anon., 1953).

Asparagus seed is slow to emerge and under some conditions it may be desirable to use a pre-germination mulch to prevent soil crusting and to conserve moisture. A mulch of straw, which should be removed as soon as the seedlings emerge, is recommended for this purpose in Argentina (Minist. Agric., Buenos Aires, 1942), and

a thin layer of compost is recommended in South Africa (Reinecke, 1953).

Established beds

Among the widely varying systems of culture for asparagus, mulching has been used for winter protection, for supplying humus and nutrients, for weed control or for forcing. Owing to the difficulty of digging manure into established asparagus beds it is often perforce applied as a surface mulch, the covering effects being considered as secondary. Surface dunging in the autumn is a very old custom and was recommended by Miller (1757, 1759) to " preserve the Ground in Heart to maintain your Roots in Vigour". Miller protested strongly against the long-prevailing opinion that dung communicates a strong, rank taste to asparagus, and went so far as to prove the error in the following experiment : " I planted two Beds of Asparagus, upon Ground which had Dung laid a Foot thick ; and these Beds were every Year dunged extremely thick, and the Asparagus produced from these Beds was much sweeter than any I could procure, though they were boiled together in the same Water." Another objection to dunging was later raised by Dickson (1826) : " He had observed that the usual mode of dressing Asparagus beds by a covering of dung in winter on the surface was apt to produce cankers and that consequently many of the plants in the beds came up sickly and weak in spring, and ultimately decayed during the summer." In spite of this, autumn mulching with manure seems to have been a practice much favoured by 19th-century gardeners, as a couple of quotations from Loudon's *Encyclopaedia* (1935) will show : " Nicol recommends covering asparagus-beds with good dung, and not mere litter, as frequently is done, in the idea that the roots would otherwise perish. Fresh dung mixed with sea-weed he considers the very best manure for asparagus " ; and " Neill mentions a very proper precaution before covering, which is, to stir the surface of the beds with a fork, in order that the juices of the manure washed down by the rains may be readily imbibed. He adds, that some cover the manure with a thin layer of earth from the alleys, which is called *landing up*." This autumn dunging was not merely an English custom. Loudon mentions that the French cover in autumn with 6 inches of dung and 4 of sand, and Baumann (1824) describes how in Austria asparagus was planted in shallow trenches and mulched before frost set in with 2 inches of old neat's dung, the coarser remains of which were cleared away in spring and the finer parts mixed with the soil. Alternatively it was planted on raised beds and the autumn dung mulch was worked in each spring until the crowns were covered by a 6-8 inch layer, after which it was allowed to lie through the winter but was cleared off each spring. These mulches thus served both as winter protection and as a source of nutrients.

In modern practice winter protection is not always considered

necessary but where it is provided a variety of materials have been used. Weaver and Bruner (1927) say : "The dead tops, if not removed, afford protection for the roots in winter, holding snow and preventing sudden fluctuation in soil temperature. This is very important in cold climates where the tops are usually supplemented or replaced by a mulch of straw or other material." Where the tops are left on as a mulch it has been recommended to flatten them down with heavy disks in the autumn to assist rotting and to disk them into the soil in the spring (Evans, 1941). Some growers prefer to remove or burn the fern in autumn to prevent seeding, but this is generally considered a waste of organic matter, and the use of the tops for soil protection is claimed by Washington growers to increase yields by as much as 1 ton per acre (Schnellhardt, 1944). Well rotted manure, where available at a reasonable cost, is commonly applied as a mulch among the dead fern in autumn and both are disked in in spring. Alternatively the remaining loose litter is raked off before soiling up. Long manure is unsuitable because of the danger of introducing weed seed. Chicken manure containing large amounts of litter is recommended by Hopp (1954) as a valuable mulch. There is, however, considerable controversy over the value of applying manure to established asparagus beds. Weaver and Bruner (1927) state that the amount of humus afforded by the continual decay of the fleshy roots, supplemented by the tops, is so great that the continued use of manure is sometimes apparently not beneficial. Nevertheless many growers consider a top dressing of manure beneficial, especially in the early years of a planting, not only to supply humus but also to assist in the maintenance of moisture and to keep the surface soil open. In trials in Nebraska (1935 and 1936) both straw and manure mulches retarded the cutting season and reduced yields although they increased the size of the spears ; manure gave better results than straw. Experiments in Maryland showed that on a fairly fertile sandy loam 20 tons of stable manure per acre per year did not increase yields sufficiently to pay for the cost of the manure, and that chemical fertilizers gave larger increases (White and Boswell, 1929). On Long Island, however, on soil in a low state of fertility, 20 tons of manure+128 lb. P_2O_5 per acre produced considerably larger yields than did the best fertilizer treatment, although the use of manure was still not profitable owing to its high cost (Wessels and Thompson, 1937). The decisive factors appear to be soil character and cost of manure.

Other materials that are sometimes applied as a mulch for winter protection are grass clippings, compost or, on heavy clay soils, a layer of sand (Hopp, 1954).

In Italy excellent results have been reported from mulching in winter with asphalt paper (Bassi, 1930). The paper was laid down from November to the end of January, according to the locality, and left in place until the beginning of March when the beds were earthed up. In some places where earthing up was done in November

the paper was allowed to remain on the beds until the first shoots appeared. The higher soil temperatures under the paper forced the asparagus into growth more rapidly so that cutting started 8-15 days earlier. It is reported that in one place the yield increase due to paper mulching was 20 per cent and in another place it was 15 quintals per 1,000m² (or about 6 tons per acre).

During the growing season the various systems of earthing up used to blanch the shoots and to suppress weeds are, in effect, forms of mulching with soil. Mulching proper, however, is rarely practised at this season on a commercial scale although sawdust mulching has been tried for weed control at some places in New Zealand ; one grower at Tauranga claims to have successfully controlled weeds without damage to the plants by three 3-inch dressings of sawdust per year, but similar attempts at Hastings have caused rotting of the plants (Bennett, 1955). Summer mulching, however, has sometimes been recommended for private gardeners. Raymond *et al.* (1954), from Cornell, say : " In the home garden weed control can be greatly simplified by the use of a loose mulch. Sawdust, wood chips, buckwheat hulls, shavings, ground corncobs and various other materials can be used to shut out weed growth but still permit asparagus spears to come through." Webster *et al.* (1954) also mention that asparagus has done well under a sawdust mulch in home gardens in British Columbia, and Woods (1956) points out that relatively permanent mulches such as sawdust have the great merit of simplicity for perennial crops like asparagus.

A special method of mulching during the growing season, for the purpose of forcing *in situ*, is practised in the Albenga district of Italy (Allegri, 1929 ; Minist. Agric., Lond., 1939). Before growth starts the beds are covered to a depth of 25-30 cm. with a layer of cotton waste from the factories at Genoa. The cotton waste is periodically watered and soon starts to ferment, producing enough heat to force the asparagus shoots. The temperature of the fermenting mass should be maintained at about 40° C., and can be controlled by regulating the thickness of the mulch and the frequency of watering. These forced beds are often covered with moveable glasshouses. The time of forcing is regulated to ensure a continuous supply of asparagus on the market over a long period. It is claimed that by this method the yield should reach 2 kg. per m², and that a bed can be forced for 4-5 years before yields fall off. In the Ministry Bulletin (Minist. Agric., Lond., 1939) it is observed that " this method has proved so successful that it is being tested in the south of France, and should be of interest to growers in England, where a supply of cotton waste is obtainable largely from the Lancashire factory areas".

CHAPTER 3

BRASSICAS

General

Cabbages are a hardy, accommodating race with a relatively low acre value. Under most conditions mulching would be wasted on them. They enjoy a firm, compact soil, so it is unlikely that the more open structure found under a mulch would in their case be beneficial. Warm conditions are not required and crops can be harvested at almost any season of the year merely by a suitable choice of variety and sowing date. Only with spring cabbage would it be of any real advantage to hasten maturity by using a soil-warming mulch. They do, however, need a good supply of moisture, and it is in districts where moisture conservation is a problem that mulching is most likely to prove worth while. Cauliflowers and broccoli, on the other hand, are more valuable and more fastidious crops, at times a warm soil is desirable, and a constant water supply is of prime importance to prevent buttoning.

Until the present century mulches seem only to have been used on the brassica crops in special cases for frost protection. Philip Miller (1759), that greatest of 18th-century gardeners, refers to them only in relation to cabbage seed plants which have been heeled in for the winter, advising " if the Winter should prove very hard, you must lay a little Straw or Pease Haulm lightly upon them, to secure them from the Frost ; taking it off as often as the Weather proves mild, lest by keeping them too close they should rot". John Loudon (1835) recommends the following methods for protecting broccoli during winter : " Each separate row might have a row of the fronds of the spruce fir placed on each side of it, meeting in the middle, so as completely to protect the plants. Mulching them close to their necks with fern would, probably, produce the same effect." At the end of the 19th century winter mulching was still being recommended for broccoli : " Additional protection is sometimes needed in the shape of light litter scattered over the heads in very severe weather." (Wright and Wright [undated].)

Mulching for winter protection no longer seems to be used for the brassicas, at least commercially, probably owing to the labour of removing the mulch during mild weather. During the last 50 years, however, summer mulches of various kinds have been attracting attention, and the brassicas have often been among the test crops used in the numerous experiments. Their response has been inconsistent and generally small.

Effects of Mulching

On yield

The earliest report on straw mulching of cabbages comes from the hot, central state of Nebraska (Emerson, 1903). In a 3-year experiment a 4-inch layer of straw was applied 2-4 weeks after planting. The results were recorded as " on the whole favourable " and cabbage is included among the crops for which strawing is considered desirable. But it is noted that strawing was better in a normal or dry year than in a wet one. This tendency is confirmed by later work in Nebraska (Werner, 1933) in which early cabbage was strawed for five years in succession, but the picture as a whole was less favourable. Only in one season, when there was a hot, dry period in May and early June, did strawing increase the yield of both the irrigated and the dryland crops. In a normal season only the dryland crop was benefited, and in years when May was wet and cold strawing definitely reduced yields. Cauliflowers, grown only in the two seasons with a wet May, also gave lower yields on the strawed plots. The brassicas were among the few crops that responded consistently to the application of additional nitrogen with the straw. In trials in Ohio over a period with high average rainfall strawing reduced the yield of cabbage by an average of 17·1 per cent (Gourley and Magruder, 1924). The mulched plants had a yellowish appearance, and as the soil was of low fertility it was suggested that nitrogen deficiency might be partly responsible for the low yields. In the northern state of Montana, however, cabbage and cauliflower were among the few crops that responded favourably to straw mulching (Montana, 1915, 1916, 1917). One can only assume that the reduction in soil temperature, which would be detrimental to the heat-loving crops, did not affect the brassicas. More information on soil moisture, however, is required to account for the positive effect of the mulch.

It has been said that a layer of rotted manure applied after planting is particularly valuable for dwarf cauliflowers as it keeps the soil open and damp and provides nutrients ; moreover, on decomposition it emits carbon dioxide which favours growth and earliness (Löbner, 1927). It is surprising, therefore, to learn that in some places in Israel bedding straw from poultry houses has caused serious losses of cauliflowers which did well under clean straw (Borovsky, 1947). A possible explanation is that the litter was applied too fresh.

In Nyasaland all vegetables, and especially brassicas, are mulched as a standard practice to conserve irrigation water (Hoyle, 1955). Dry tall grass or strawy stable manure is used, being applied when the plants are 2-3 inches high. The practice appears to have a good effect on yield but no experimental work has been done on the subject.

With other " loose " organic materials soil moisture has also

frequently been the deciding factor in yield response. Corn fodder mulch was used on sprouting broccoli in Pennsylvania in a season when August rainfall was very low (Isenberg and Odland, 1950). Soil moisture in the clean cultivated plots fell below the wilting range of 11 per cent during this drought period, but under mulch it never dropped below 12·5 per cent. The broccoli plants showed a marked response to mulching, giving a yield increase of 45 per cent where no nitrogen was added and 19 per cent with nitrogen. Yields from the mulched plots that had received nitrogen were significantly higher than those from the unfertilized mulched plots. Broccoli, which is a gross feeder, was the only one among several crops tested which showed this response to nitrogen. Grass clippings or litter used on cabbage in Ohio only caused a substantial yield increase in a very dry season (Ohio, 1922). In Malaya a grass mulch 4 inches deep had no significant effect on cabbage yield compared with compost dressing, incorporation of green grass and no treatment (Smith, 1955).

In a report on sawdust mulching from Agassiz Experimental Farm, B.C., where there is a fairly high summer rainfall, it is stated that cool season crops such as cabbage are more productive, and late maturing crops such as autumn cauliflower less productive under sawdust (Fletcher *et al.*, 1952). More recent experiments, however, have shown that sawdust had no effect on the yield of cabbage there (Agassiz, B.C., 1954). At Saanichton, B.C., with a very much lower summer rainfall, the only brassica crop reported on has been cauliflower. Here, in the first year of test, late cauliflower was a complete failure under sawdust as a result of nitrogen deficiency (Woods, 1951). In later tests additional fertilizer was supplied to the sawdust plots to offset nitrogen depression. With early summer cauliflower sawdust plus nitrogen tended to be more effective when incorporated in the soil than when used as a mulch, except when the weather at planting time was dry, but with late cauliflower, set out under very dry conditions, a 2-inch sawdust mulch resulted in higher yields than either sawdust incorporated or farmyard manure (Canada, Dep. Agric., 1952 ; Webster *et al.*, 1952, 1953, 1954).

With peat and woodwool mulches results have been obtained for which little explanation is forthcoming and which are sometimes contradictory. On a moorland soil near Moscow a cover of dry peat increased yields of white cabbage by 8 per cent ; suppression of weeds is indicated as an important benefit of the mulch (Ložkin, 1935). A Czechoslovakian worker (Zlatkovský, 1952) recommends a mulch of sugar factory refuse (peat + slaked lime in a 10:1 ratio) for early cauliflowers in frames, and reports that its use favoured growth and earliness, although it did not affect total yields. In a German trial total yields of outdoor summer cauliflower on fen soil were reduced 18 per cent by a mulch of peat, the reduction being due to the smaller number of heads harvested

(Reinhold and Schmidt, 1933). In the same German trial an impregnated woodwool, known variously as Drawin or Wega mulch, decreased both number and weight of individual heads harvested, total yields being reduced by 32 per cent. Reinhold (1942) later reports on a series of trials on Wega mulch in different parts of Germany which showed that its use reduced the yield of white cabbage by an average of 12·4 per cent. Bayer (1951), however, mentions that Wega mulches have resulted in substantial yield increases with cabbage in Austria. It is not possible to draw general conclusions from the limited information available.

Outstanding success with a "loose" organic mulch was achieved on a saline solonchak soil in the Azov-Don basin (Karnauhov, 1949). On this soil a 6-8 cm. layer of freshly cut reeds resulted in a six-fold increase in the average weight of individual heads of cabbage. This good result appears to have been due very largely to the reduction by mulch of the soluble salt concentration in the root zone of the soil, for the salt concentration in the uncovered soil was so high that it caused strong retardation of growth. A better moisture supply and an improved nutrient regime were also considered to be contributory factors.

Soil covers of white sand and coke dust had no significant effect on yield of cauliflowers grown on fen soil in Germany (Reinhold and Schmidt, 1933). This is not surprising since neither mulch affected the moisture regime of the soil and temperature differences were small. In the far north of Russia a cover of soot sprayed on the soil in solution resulted in a 43 per cent yield increase with cauliflower (Banasevič, 1941). The benefit is attributed to the heat-absorbing capacity of the black soot.

Brassicas have often been included among the test crops used in paper mulching experiments but results have been extremely variable and inconsistent. With both cabbage and cauliflower a fair increase in yield has been obtained in just over half of the paper mulch trials reported. Since it is difficult from the information available to trace any consistent pattern of response to paper mulching, it would be valueless to describe the experiments in detail (see Agassiz, B.C., 1930, 1931 ; Anon., 1926, 1927 ; Bassi, 1930 ; Becker, 1926 ; Böhnert, 1926 ; Boischot and Albert, 1931 ; Boresch, 1932 ; Canada, Div. Hort., 1930b, 1931 ; Diev, 1935 ; Edmond, 1929 ; Flint, 1928 ; Florida, 1930 ; Gator-Hide Mulch Paper, 1929 ; Hutchins, 1933 ; Kapuskasing, Ont., 1930 ; Kuznecov, 1935 ; La Ferme, Quebec, 1931 ; Ložkin, 1935 ; Magruder, 1928, 1929, 1930, 1931a and b ; Moen, 1926 ; Morden, Man., 1930, 1938 ; R-., 1929 ; Reinhold and Schmidt, 1930a and b, 1933 ; Schomerus, 1931 ; Summerland, B.C., 1930 ; Thompson and Platenius, 1932 ; Torstensson, 1931 ; Werner, 1933 ; Woods, 1937).

A new development in paper mulching, which is cheaper than the use of asphalt-impregnated strips, is the use of soaked and pulverized newspaper which dries to a hard crust when spread

round the plants. This has been tested on cabbage at the Michigan State College and was said to result in good growth of the plants and weed-free plots, but no experimental data are given (Hamner and Rai, 1955).

The use of Emed-Strapazoid, a roofing felt fitted on a wire gauze framework, is worthy of mention as indicating the thoroughness with which a suitable mulching material has been sought. The material was tested at Geisenheim (Rösch, 1932) and it was found to be more resistant to damage than asphalt paper and to have the advantage that workers could walk on it. Holes were cut in the material, through which savoys, white cabbage and cauliflower were planted. A spring drought occurred soon after planting and the mulched plants grew remarkably better than the controls and produced much heavier and earlier yields. The material, however, was even more expensive than asphalt paper, and on this account Reinhold and Schmidt (1933) excluded it from their extensive mulching trials.

Aluminium foil mulch is reported to have given increased yields of broccoli in Virginia (Tiedjens, 1950) but no details are recorded. In Florida the foil increased yields of early sprouting broccoli by about 45 per cent (Burgis, 1951 ; Florida, 1949-50). It is considered that the effect was probably due to the conservation of fertilizers under the foil, as no leaching occurred. The foil also conserved moisture, reduced temperature fluctuation and controlled weeds.

On growth and maturity

Since brassicas are generally grown as transplanted crops they are not usually mulched until they reach the field stage. Two reports, however, show that suitable mulches may have a favourable effect on germination. Zlatkovský (1952) found that a mulch of peat + hydrated lime (sugar factory refuse) resulted in a more even germination of cauliflower seed in frames. Recent tests at the University of Arizona Experiment Station (Anon., 1954) have shown that vermiculite, applied as a mulch strip $\frac{1}{2}$ inch deep and 1 inch wide over the seed rows, will greatly improve germination by preventing drying out. It has been used under the hot, dry conditions of the Arizona Station to obtain perfect stands of broccoli and cauliflower where precision is needed in experimental work. The vermiculite is readily applied through a hopper and should fill the depression left by the planter shoe.

The use of bush refuse (small twigs and broken leaves of eucalyptus and leptospermum trees washed up on river banks) as a mulch on cauliflower and cabbage seedlings seriously depressed growth in experiments at Hawkesbury Agricultural College, N.S.W. (Waring, 1950). It was suggested that some toxic substance may have been released by the mulch.

Root development, on which aerial growth so largely depends,

is greatly affected by the modified temperature and moisture regime under a mulch. Musso (1932) carried out experiments with cabbage in the Leningrad area and found that a large difference between air and soil temperatures in the daytime promotes root formation. A layer of straw will increase this difference whereas a layer of black paper will reduce it in the top 10 cm. of soil. Depth of planting, therefore, made little difference to the growth of cabbage under a straw mulch, but under a black paper mulch cabbages made little growth when they were planted shallowly (6-8 cm.) but much more luxuriant growth when they were planted deeply enough for the roots to be in the cooler soil layers. The temperature difference between air and soil was also reflected in the shape of the leaves, cabbages on the strawed plots having round leaves and those on the papered plots elongated ones. The stimulating effect of straw on root growth is confirmed by Bielka and Hildebrandt (1954) in Germany who recorded an increase of 27 per cent in the dry root mass of red cabbage grown under straw. Musso's observations on the inhibiting effect of paper mulch on root growth in the upper soil layers, however, do not seem to be borne out by observations in less extreme climates. Many workers report greater surface rooting of crops under paper, due to the improved moisture conditions and lack of cultivation ; marked surface rooting of brussels sprouts, for instance, was noted by Schomerus (1927).

Top growth of cabbage, measured as weight of individual heads, was increased by strawing in Montana (Montana, 1915), but in other cases growth has been retarded owing to lower temperatures or depression of nitrogen (Gourley and Magruder, 1924 ; Werner, 1933). Sawdust mulch has also caused nitrogen depression and unhealthy growth of cauliflowers in British Columbia (Woods, 1951), but when additional nitrogen has been applied this trouble has been overcome (Webster *et al.*, 1953, 1954). Late cauliflower made quicker growth under a 2-inch mulch of sawdust + N than on plots in which manure or sawdust had been incorporated, although summer cauliflower made better growth on the sawdust incorporated plots. In Hawaii cabbage is said to have made very good growth under sawdust, but no information is given on the N supply (Swanson, 1953). In Pennsylvania a corn fodder mulch, 2-3 inches deep, caused a striking difference in the growth of sprouting broccoli, the plants being taller with broader leaves which were greener and more succulent ; the effect seemed to be largely due to conservation of moisture during a drought period (Isenberg and Odland, 1950). In this case, too, the response to extra nitrogen was significant. On a strongly saline soil a reed mulch made such a difference to the growth of cabbage plants that the weight of the heads was increased six-fold (Karnauhov, 1949). The main reason for this difference was the reduction in salt concentration in the soil under mulch, so that the mulched plants were able to develop normally, whereas the controls were retarded in growth and pale green in colour and many

of the roots died. Paper mulching has sometimes been reported to stimulate the early growth of kale, cauliflowers and cabbage (Anon., 1927 ; Werner, 1933 ; Werth, 1930) but in one case reduced growth of cabbage was noted (Florida, 1930). Heavier heads have often been the accompaniment of increased yield (Canada, Div. Hort., 1930b, 1931 ; Flint, 1928 ; Magruder, 1930 ; Schomerus, 1931), but Magruder (1931b) found that although the heads of paper mulched early cabbage were larger than the controls at the first cutting they were smaller at the second. Cabbage has been shown to be very susceptible to injury by the fumes from tarred mulch paper (Böning, 1926).

It has been said that a mulch of rotted manure will favour earliness in cauliflower as a result of the carbon dioxide which is emitted during decomposition (Löbner, 1927). This question of carbon dioxide production and the effect of mulches on carbon dioxide release from the soil is one that has received comparatively little scientific attention. A mulch of peat and lime has also been found to increase earliness of cauliflower in frames (Zlatkovský, 1952). In a report on sawdust mulching from Agassiz, B.C., Fletcher *et al.* (1952) point out that as sawdust tends to delay maturity it cannot be recommended for late season crops, such as autumn cauliflower or cabbage, unless a late harvest is desired. In a trial at Saanichton, B.C., however, autumn cauliflower grown under a 2-inch mulch of sawdust was ready for cutting about a month earlier than unmulched plants grown on soil treated with farmyard manure owing to more rapid growth and larger heads (Webster *et al.*, 1954). A 4-inch layer of sawdust incorporated in the soil in the spring favoured earliness almost as much as the mulch, but a 1-inch layer incorporated was much less effective. With summer cauliflower there was little difference in time of cutting between treatments. Roofing felt, Emed-Strapazoid, produced much earlier yields of cabbage, savoy and cauliflower (Rösch, 1932). In many of the paper mulching trials with brassicas earlier yields, or heavier yields during the first part of the harvest season, have been reported (Agassiz, B.C., 1930, 1931 ; Becker, 1926 ; Boischot, 1930 ; Gator-Hide Mulch Paper, 1929 ; La Ferme, Quebec, 1931 ; Morden, Man., 1930 ; Reinhold and Schmidt, 1930a ; Schomerus, 1931 ; Werner, 1933 ; Woods, 1937). In a few trials paper did not favour earliness (Anon., 1926 ; Boischot and Albert, 1931 ; Moen, 1926 ; Thompson and Platenius, 1932). Magruder (1928) found that maturity was advanced in late but not in early cabbage. In Canadian trials cabbage was slightly earlier under paper in one year but not in the next, whereas maturity of cauliflower was unaffected (Canada, Div. Hort., 1930b, 1931).

On quality

Apart from references to the effect of mulching on the size of the heads [see under *Growth and maturity*], information on the

quality of mulched brassica crops is negligible, and what does exist is frequently expressed in such general terms as to be almost valueless. For instance, it has been reported that straw mulched cauliflower produced better quality heads than clean cultivated plants (Montana, 1916). With summer cauliflower grown under very dry conditions, the best heads were cut from sawdust mulched plots, the other treatments being farmyard manure and sawdust incorporated in the soil (Webster *et al.*, 1952). In German trials quality of cabbage was unaffected by a Wega woodwool mulch (Reinhold, 1942). Magruder (1930) observed that although paper mulching produced larger and heavier heads of early cabbage, the heads were less solid than those on the control plots. He considers that the high moisture content of the soil under paper caused excessively rapid growth. In the same trial the quality of early cauliflower was unaffected by paper mulching. Edmond (1929), however, noticed that cabbage grown under mulch paper produced heads as solid as those grown with clean cultivation.

On pests and diseases

Karnauhov (1949) mentions that cabbage plants grown on strongly saline soil suffered considerably more from attack by pests when unmulched than when mulched with reeds. This greater resistance of the mulched plants is not accounted for, but was presumably associated with the lower concentration of salts under the mulch which allowed normal, healthy growth.

Emerson (1903) made the passing observation that grasshopper attack was more severe on straw mulched plots of late cabbage than on clean cultivated plots.

Mulch paper laid in strips between each row of plants does not appear to prevent damage by cabbage root fly, for in a Canadian trial root maggots were as bad on the mulched as on the control plots of cauliflower in each of two seasons (Canada, Div. Hort., 1930b, 1931). This is not surprising since the soil around the plant bases, where the eggs are usually laid, is left uncovered by paper strips. Paper collars around the base of the plants have sometimes been recommended to prevent oviposition by cabbage root fly, but their use is so specific that they can scarcely be considered as a mulch. A bituminous mulch emulsion, on the other hand, which is sprayed over the whole surface of the soil and has been tested as a means of controlling erosion in Russia, was found to prevent egg-laying very successfully (Banasevič, 1935, 1941). In other respects, however, particularly in its failure to give adequate weed control, the bituminous emulsion was considered to be an unsuitable form of mulch for cabbage.

In the extensive series of investigations made in Florida on the effect of mulches on the root-knot nematode (Florida, 1938-1951), broccoli was among the test plants used. Higher yields of broccoli were obtained from the plots mulched with a deep layer of forest

leaves than from those mulched with miscellaneous plant material, or from the clean cultivated plots. Vegetative growth was equally vigorous with the two types of mulching material, while growth on the unmulched plots was decidedly inferior. It appeared, however, that although mulching improved the growth and yield of plants on root-knot infested soil it did not control the nematodes.

Economics

Since brassicas, with the possible exception of cauliflowers and broccoli, have a comparatively low acre value and are tolerant of a wide range of soil conditions, it would clearly not pay to use expensive mulching materials on them. Synthetic materials, such as asphalt paper, roofing felt and impregnated woodwool, are generally expensive. By far the greatest majority of workers have come to the conclusion that the use of paper mulch will only be economically justified on high value, heat-loving crops. In exceptional cases, however, the yield response of brassicas, notably early cabbage and cauliflower, has been high enough to cover the additional cost. Reinhold and Schmidt (1930a and b), for instance, calculated that the use of paper was profitable on early red cabbage grown on peat soil in Germany owing to the much higher early yield when prices were good. Magruder (1931a) also considered paper mulching to be profitable for early cabbage in Ohio, and Diev (1935) for cauliflower in Russia. These opinions, however, are not general.

Conclusions

The use of mulches on the brassica crops appears to be best justified as a moisture conserving measure in districts where summer droughts are a problem. For this purpose natural organic materials such as straw, corn fodder, sawdust and peat have at times proved satisfactory and increased yields. Brassicas are particularly liable to suffer from the reduced nitrate supply under such mulches and additional nitrogen may be needed to compensate for this.

Under certain special conditions unfavourable for growth, namely on strongly saline soils or root-knot infested soils, mulches of plant residues have resulted in a marked improvement in growth.

A surface layer of soot has been known to increase yields of cauliflower in a cold climate by increasing soil temperature.

Artificial heat-absorbing mulch materials, such as asphalt paper, roofing felt and impregnated woodwool, have sometimes, but not consistently, increased earliness and yield of the brassica crops. Except possibly in the case of early cabbage and cauliflower, their use is not likely to be economic owing to the high cost of the materials and the low value of the crops.

In recent tests aluminium foil has given excellent results with broccoli, probably owing to conservation of fertilizers.

Vermiculite has improved germination of brassicas in a hot, dry climate by preventing drying out of the soil. Its commercial value does not appear to have been investigated.

A bituminous mulch emulsion has proved effective in preventing egglaying by the cabbage root fly, but in other respects this is not considered a satisfactory mulch for brassicas.

CHAPTER 4

CUCURBITS

General

English growers naturally tend to think of cucumbers and melons mainly as glasshouse or frame crops, but in a great many warmer countries open air culture is the normal commercial practice. In fact almost all the work on mulching has been done on the outdoor crop, and in this section the outdoor crop is the one under consideration unless glasshouse culture is specifically mentioned.

Because of their trailing habit of growth, the presence of a protective layer of mulch between the soil and the plants has a special value for these vine crops. Not only does it keep the fruit clean, but it helps to prevent fruit rots and foliage diseases caused by contact with the damp soil [see under *Pests and diseases*].

The cucurbits are all tender, warm season crops, and the requirements of the different species vary mainly in length of growing season and degree of atmospheric humidity. Cucumbers have a short growing season of only 60-70 days, and as the fruit is harvested at an immature stage they do not need such hot, dry conditions as melons. The roots of cucumbers, however, are known to be killed when the soil temperature drops below 60° F., so in northern countries organic mulches may tend to keep the soil too cool. A constant supply of soil water is needed to keep the vines growing and producing fruit unchecked. In this respect most types of mulch are advantageous, and would be desirable either as a substitute for or supplement to overhead irrigation, for irrigation not only favours the development of foliage diseases but tends to cause panning and crusting of exposed soil. Cucumbers appear to have a special partiality for loose, well aerated soil, provided it is retentive of moisture, and the improved soil conditions under mulch, particularly where irrigation is used, appear to be largely responsible for the good effects of mulching on this crop.

Muskmelons require a longer growing season, of about 80-100 days under favourable conditions. This fact makes it difficult to grow them successfully in the open in northern districts, and the use of black paper mulch, which tends to increase the temperature and hasten maturity, has helped to extend the range of their culture considerably. For instance, von Wrangell (1929a) states that melons cannot be grown out of doors in Germany in the normal way, but by the use of paper mulch it was possible to mature good crops. The same was found in Czechoslovakia (Boresch, 1932) and British Columbia (Standen, 1930 ; Straight, 1938). Aluminium foil mulch has also proved useful for extending the growing range of

melons, for although this material decreases the soil temperature during hot sunny days it increases it at night and has advanced maturity of melons by as much as two weeks. In trials at the Virginia Truck Experiment Station (Wall, 1950) it was found possible to grow 103 varieties of melon successfully with aluminium foil mulch, whereas only 9 varieties succeeded on the unmulched plots. In addition to a long growing season, muskmelons require hot, arid conditions for the fruit to ripen and develop the best flavour. In America they are mainly grown in the dry south-western states under furrow irrigation, as overhead irrigation would increase atmospheric humidity which would not only be detrimental to fruit quality but would favour the development of diseases. The technical difficulties of mulching in conjunction with furrow irrigation make it unlikely that the practice can be used commercially in these large production areas, in spite of the fact that it has proved very successful in less specialized districts.

Watermelons need an even longer growing period than muskmelons, but are more tolerant of atmospheric humidity. Pumpkins and squashes can be grown under cooler conditions than melons.

Mulching appears to be a very ancient practice with melons, the old Chinese custom of pebble mulching being applied particularly to watermelon and cantaloupe fields, where it was used primarily to conserve the very scanty supply of moisture (Rodale, 1949). Gravel was dug from the river beds and spread over the fields to a depth of 3-4 inches.

It is interesting to note that various types of soil covering were also used for melons in England over 100 years ago, in an attempt to keep the fruit clean and dry and to assist ripening. John Williams (1824) describes a method of growing melons in the open in the north of England. This consisted in the construction of a raised hot bed, sloping towards the south, the surface of which was covered with slates. He explains that " slates answer much better as a covering to the mould than tiles, as they are dry in a few minutes after a shower, and their dark colour absorbs more heat ". He adds : " The whole contrivance for presenting the plant to the solar influence in the most advantageous way, and at the same time giving a little warmth to the roots, does not cost more than a few shillings." In a later paper on melon culture Williams (1842) again recommends the use of slates to increase the temperature under a glass cover without sides. Loudon, in his *Encyclopaedia of Gardening* (1835), says of melons : "As the fruit increases to the size of a walnut, place a flat tile or slate under each, to protect it from the damp of the earth ; the slab thus interposed will also assist the fruit to ripen, by reflecting the rays of the sun." Organic mulches were also recommended for melons by the gardeners of that time. Greenshields (1830) says : " The bed should be covered over with a layer of short grass, or any dry litter that may be most convenient, to keep the vines and fruit

clean." In Germany, too, soil covering was long ago used in an attempt to grow melons successfully out of doors. Wollny (1897-98) cites the following example : " Johnson, writing in 1872, mentions that melons have been ripened in the open in Saxony, even in cool summers, by covering the soil with a 2·5 cm. layer of coal dust." These early experiments with the heat absorbing slates and coal dust were an attempt to do what modern growers have been doing on a much more extensive scale with black paper mulches.

Effects of Mulching

On yield

A report from Ohio (Marion, 1933) states that manure mulches have consistently reduced yields of greenhouse cucumbers owing to the depletion of soil nitrogen that occurs during decomposition of the manure. In spite of this some growers continued to use them in order to reduce run off of water and prevent baking and cracking of heavy soils. It was suggested that a leguminous material containing a higher proportion of nitrogen to carbohydrates might achieve the good effects of mulching without causing nitrogen deficiency. Clover chaff was selected for trial because it was fairly cheap and available in large quantities. The nitrogen: carbohydrate ratio of the chaff was 1:16 whereas that of horse manure was 1:40. Both spring and autumn crops of greenhouse cucumbers mulched with clover chaff, at the rate of 6-8 tons per acre, produced good crops of high quality fruit, and no signs of nitrogen starvation were observed. No comparison was made with unmulched crops, but Marion mentions that all growers who had tried clover chaff mulch were very pleased with the results, and concludes that it is the best and cheapest material available.

In spite of the fact that they thrive best under warm conditions, the outdoor vine crops have often responded very well to the loose organic types of mulch which tend to keep the soil cooler by day. This has especially been the case in warm districts where the limiting factor to good growth is not low temperature but lack of a constant supply of soil moisture. Under such conditions it does not seem to matter what type of mulch material is used so long as it effectively increases the soil moisture content. An interesting experiment confirming this theory was carried out at the Pennsylvania Agricultural Experiment Station (Isenberg and Odland, 1950) where the performance of cucumbers grown under five different mulch materials was compared with that under clean cultivation. The mulch materials used were straw, sawdust, leaves, grass clippings and cow manure. All the treatments gave large increases in yield, ranging from 86 per cent for grass clippings to 135 per cent for leaves, but the differences between the individual materials were not statistically significant. Nitrogen treatments did not affect the

results. Soil moisture determinations, made during a very dry period when the vines on the cultivated plot were wilting, showed that the moisture percentage was much higher under all the mulches than in the cultivated soil and was well above the wilting range. The authors consider that the increased yields were very probably due to the ability of the mulched plants to continue uninterrupted growth when the cultivated plants suffered a check, to the greater root development in the upper soil layer which contains the highest concentration of nutrients, and possibly to the cooler root run during mid-summer. They point out that the increases could not be attributed to any great extent to the fertilizer value of the mulches themselves, as the materials used varied widely in fertilizer value yet their effects on yield were not significantly different.

These results are in accordance with those of most other experiments made in warm, dry districts. In Nebraska, Ohio and Missouri, for instance, yields of cucumbers, muskmelons or watermelons have all been favourably affected by strawing (Emerson, 1903 ; Gourley and Magruder, 1924 ; Rosa, 1923 ; Werner, 1933). In southern Rhodesia a mulch of oyster nuts (*Telfairia*) has been used on cucurbits with great success (Hayter, 1955). In Israel, where overhead irrigation was used, mulching cucumbers and squashes with dry weeds, straw or cotton seed waste mixed with straw not only improved yields but also reduced the amount of irrigation water needed by one-third to one-half (Griss, 1949). Better soil structure and a much greater concentration of roots in the upper 10 cm. layer of soil under mulch was again noted in the case of cucumbers. In these experiments weed mulch gave a considerably smaller increase in cucumber yields than straw, but this is accounted for by the fact that the former crop was spring sown and therefore grown under much more favourable conditions than the straw mulched summer crop. Confirmation of the good effects of straw and weed mulches on cucumber yields and for water conservation also comes from growers in Israel, though without experimental evidence (Crispin, 1943 ; Mordechai, 1943). On the other hand, one report from the Government Experiment Station at Acre states that neither hay nor compost mulching had any effect on the yield of cucumbers although other vegetables responded favourably (Aharonovitch and Ulman, 1947). No explanation is suggested for this anomaly. In Hawaii a mulch of cane bagasse has been successfully used on furrow-irrigated cucumbers (Gilbert, 1956).

In cooler areas, such as the northern states of America and Canada, organic mulches have not proved so successful. In Montana, for instance, cucumbers, pumpkins and squashes did better under clean cultivation than under straw mulch, because the lower soil temperature under straw had a greater effect on growth than the increased soil moisture (Montana, 1915-1917). In New Jersey, also, yields of cucumbers mulched with old hay were slightly lower than

those of the controls even in a year when there was a severe drought in late summer. In a hot, wet season mulching with fresh hay, salt hay or excelsior woodwool had no effect at all on yield, presumably because water conservation was not necessary and temperatures were high enough for a reduction by mulch not to affect growth (New Jersey, 1896, 1897). In British Columbia, where sawdust is widely used as a mulch for vegetables, heat-loving crops are said to have responded less well than early, cool season crops (Fletcher *et al.*, 1952). The only experimental evidence available, however, shows that a sawdust mulch did tend to increase yields of squash (Woods, 1951).

In Europe, the loose, voluminous mulches appear to have been tested only on cucumbers among the vine crops, and here the results have varied greatly. Nikolaisen (1925-26) in Germany used peat in a cold, wet season with the result that the mulched crop yielded only 9·6 per cent of the controls. Reinhold and Schmidt (1933) tested various types of loose mulch at Grossbeeren on a moist moorland soil. Peat, woodwool, coke dust and sand all had a detrimental effect on yield ; all the materials except sand tended to reduce soil temperature and respiration, while only peat and woodwool increased soil moisture content. In a later series of trials in Germany (Reinhold, 1942) Wega woodwool reduced yields of cucumbers on the average by 14·6 per cent, whereas in Austrian trials it gave average yield increases of 56 per cent and 30 per cent (Bayer, 1951 ; Kopetz, 1935a). These reports do not tell one enough about the soil and weather conditions to permit of generalization, but it seems probable that the best results from organic mulches would generally be obtained under dry conditions. Evidence to support this comes from two trials carried out on poor sandy soil. In the first, at Seyda, a layer of pine needles the depth of a hand gave good results over several years and the cucumber vines remained green even longer than those mulched with manure (Murawski, 1931). In the other, at Leipzig, a 34 per cent yield increase was obtained from mulching with a 3 cm. layer of straw (Bielka and Hildebrandt, 1954). The authors attribute the good effect to improved soil conditions, resulting in greater root development and better utilization of nutrients. Also under irrigated conditions, however, organic mulches may be of value in improving soil structure and aeration, though the benefit would probably be less spectacular in temperate than in very hot climates. Irrigated cucumbers at Geisenheim gave a 20 per cent increase in yield as a result of mulching with a 10 cm. layer of hay (Geisenheim, 1954).

During the inter-war period asphalt paper mulch, which at that time was causing a minor sensation in the horticultural world, was very widely tested on all the vine crops. Indeed, the cucurbits have been the crops responding best to this type of soil cover. [See Fig. 8.] A survey of the literature shows that in almost every case paper mulching has resulted in higher yields, and frequently the covered

crops have produced from twice to six times as much as the controls (Agassiz, B.C., 1931, 1937 ; Anon., 1926 ; Bassi, 1930 ; Becker, 1926, 1927 ; Böhnert, 1926 ; Boischot and Albert, 1931 ; Boresch, 1932 ; von Bronsart, 1931 ; Canada, Div. Hort., 1930b, 1931, 1936 ; Diev, 1935 ; Eckart, 1923 ; Edmond, 1929 ; Eggert, 1926 ; Flint, 1928 ; Florida, 1930 ; Fredericton, N.B., 1930 ; Graefe, 1924 ; Hilton and Giffen, 1950 ; Hutchins, 1933 ; Indian Head, Sask., 1931 ; Jensen, 1926 ; Kuznecov, 1935 ; Langer, 1927 ; Lerch, 1930 ; Magruder, 1928, 1929, 1930, 1931a and b ; Marchi, 1929 ; Moen, 1926, 1929 ; Morden, Man., 1930, 1938 ; Musso, 1932 ; Nikolaisen, 1925-26 ; Oregon, 1952 ; Otto, 1926 ; Papworth, 1930 ; Reinhold and Schmidt, 1930a and b, 1933 ; Rhode Island, 1930 ; Robb, 1929 ; Rubin, 1935 ; Saanichton, B.C., 1937 ; Schomerus, 1927 ; Sidney, B.C., 1929 ; Standen, 1936 ; Summerland, B.C., 1931 ; Thompson and Platenius, 1932 ; Weihenstephan, 1929 ; Werner, 1933 ; v. Wrangell, 1928, 1929a and b ; Woods, 1937). Among the factors that appear to have been chiefly responsible for the good effects of paper mulching on yield are warmer soils, higher air temperature, better supply of moisture especially on heavy or humus soils in dry seasons, more rapid nitrification and better soil structure. Being low growing crops, the cucurbits are specially able to benefit from the higher temperature of the air layer just above the paper. In the few cases in which yields have been unaffected or slightly reduced by paper mulch, the summers have generally been cold or wet (Langer, 1927 ; Lerch, 1930 ; Moen, 1929). Moen discusses the causes of failure in a report on the results of trials in two very different seasons. In Norway, during a summer hotter than average, cucumber yields were increased by 67 per cent as a result of paper mulching, while in an exceptionally cold season the cover had practically no effect on yield ; similar results are quoted from Sweden. He considers that paper mulching is more likely to be effective in warm regions than in northern countries, and that in the north the greatest benefit will be obtained in areas with low rainfall and warm summers.

There is one interesting case of paper mulching proving harmful to cucumbers in a hot dry season in Germany which is an exception to the above generalization (Reinhold and Schmidt, 1930a). In this trial, on rather dry sandy soil, cucumbers planted out onto a plot covered with Natronag paper yielded 30·3 per cent less than those planted on uncovered soil, whereas cucumbers sown *in situ* gave a 63 per cent yield increase in favour of mulching. The authors suggest that the failure of transplanted cucumbers was due to the higher air temperature on the covered plots, the lower air humidity and the fumes emitted by the freshly laid paper during the sunny weather. Sown cucumbers were able to acclimatize themselves gradually to these conditions, and moreover the fumes from the paper would have disappeared before the seedlings emerged. That the hot, dry air was more detrimental to the plants on dry soil

is shown by the fact that there was a greater reduction in yield on ploughed than on harrowed sandy soil, while on moist humus soil cucumbers even responded favourably to paper mulching. The authors recommend that sensitive crops such as cucumbers should only be planted out onto paper covered plots during overcast or rainy weather.

Light-reflecting types of mulch have generally given good results with cucumbers and melons, which appear to respond well to increased radiation. In the only test with light coloured paper, carried out in Ohio, cucumber yields were increased more by the light paper (59 per cent) than by the black (44 per cent) (Magruder, 1930). Aluminium foil produced very favourable responses with both cucumbers and muskmelons in Virginia (Tiedjens, 1950 ; Wall, 1950) although no actual figures are reported. On the other hand, aluminium foil had no effect on cucumber yields in a test at Geisenheim (Weger, 1951a, 1952), in spite of the fact that the light reflection from the foil was four times as great as that from soil. This lack of response is attributed to the exceptionally warm, moist season which so favoured the growth of cucumbers that even the controls produced abnormally heavy crops.

Encouraged by the good effect that certain light-reflecting mulches had been shown to have on the development of many crops, Weger (1953) decided to investigate the effect of covering the soil with glass. This reflected a large amount of the light falling on it and even in dull weather there was strong reflection of dispersed light. Cucumbers and tomatoes were used as the test crops, and the glass cover consisted of ordinary Dutch lights laid lengthwise along either side of the plant rows and inclined at an angle of 5° towards the plants. An uncovered strip, 10 cm. in width, was left for the plants and there was an air space of about 3 cm. between the soil surface and the glass. As the glass was not laid directly on the soil surface it cannot strictly be called a mulch, but this is merely a purist objection and the effects produced are certainly relevant to a study of mulching. Laying the glass at a slight angle ensured that the maximum amount of light was reflected onto the plants, and that the rain or irrigation water would run off the glass onto the soil around the plants. The test season was one of exceptional drought until mid-August, necessitating heavy irrigation, after which a rainy period set in. Briefly, the soil under the glass was warmer during the early part of the season, but slightly cooler after the vines had covered the glass, than the controls. As might be expected, the top 10 cm. layer of soil was always drier under the glass than in the controls, but below this depth there was little difference in moisture content, owing to prevention of evaporation and to seepage of water from the plant rows. The soil in the plant rows between the lights was always wetter than in the uncovered plots because of the accumulation of water which ran off the glass. The air space between the soil and the glass acted as a trap for both

heat and moisture vapour. Both crops responded very favourably to this drastic modification of the microclimate, cucumbers giving a yield increase of 63 per cent. Weger points out that the good effect on growth and yield cannot be attributed to any single factor, but the better soil conditions under the glass appear to have been of very great importance. The heavy and frequent irrigation during the hot season caused a panning and crusting of the soil on the control plots which did not occur under the covers, with the result that root development was better under the glass. He also suggests that the increased radiation might have resulted in a higher reproductive capacity of the plants, in accordance with the results of earlier experiments. This possible effect of radiation on reproductive capacity is clearly a point which deserves attention.

On growth and maturity

A soil cover of vermiculite has been used experimentally to improve emergence of cantaloupe seed in the hot, dry climate of Arizona (Anon., 1954). It was applied $\frac{1}{2}$-1 inch deep in a band along the seed rows: it effectively insulated the soil and prevented drying out and crusting.

There are many reports of the germination of cucumbers and melons being more rapid when black paper mulch was used (Canada, Div. Hort., 1930b, 1931 ; Hutchins, 1933 ; Magruder, 1928, 1930, 1931a and b ; Morden, Man., 1930 ; Musso, 1932 ; Werner, 1933), the difference in time of emergence generally being 1-3 days. The Russian author, Musso, mentions that although germination was quicker on the paper covered plots the seedlings even of such heat-loving plants as cucumbers often died within a few days because the surface layer of soil was too hot. This would presumably only happen in very extreme climates as it has not been reported by other authors. Musso goes on to say that when cucumbers are well established, and the roots have penetrated to the deeper, cooler layers of soil, the plants will not be injured by paper mulch and will respond with luxuriant growth. More vigorous vegetative growth under paper seems to be a fairly generally observed response with the vine crops. Von Bronsart (1931) mentions that plant weight of cucumbers was increased by 62 per cent on unmanured plots and almost as much on manured plots as a result of the greater micro-activity and nitrate production in the paper covered soil ; nitrate determinations showed that the covered plots had a higher nitrate content in spite of the more vigorous growth and consequently greater utilization of nutrients. In this trial there was little difference in the moisture content of the soil in the two treatments, but it is probable that in many cases a better water supply under paper, as well as higher activity of microorganisms, may be responsible for the more vigorous growth. In two exceptionally dry years in Italy, for instance, paper mulched cucumber and melon plants grew strongly and remained green until autumn, whereas the control

plants were killed by drought (Bassi, 1930). Stimulation of growth by asphalt paper is confirmed from many other sources (Agassiz, B.C., 1930 ; Anon., 1926 ; Boischot and Albert, 1931 ; Canada, Div. Hort., 1930b, 1931 ; Flint, 1928 ; Hilton and Giffen, 1950 ; Hutchins, 1933 ; Jensen, 1926 ; Morden, Man., 1930 ; Oregon, 1952 ; Papworth, 1930 ; Reinhold and Schmidt, 1930a ; Schomerus, 1927 ; Sidney, B.C., 1929 ; Weihenstephan, 1929 ; Werner, 1933 ; v. Wrangell, 1929a). On the other hand, reduced growth of cucumbers, watermelons and cantaloupes under paper is reported from Florida (Florida, 1930), and Langer (1927) mentions that in a very wet season mulched cucumbers appeared unhealthy and developed brown leaves and many deformed fruits. Reinhold and Schmidt (1930a) warn growers against transplanting cucumbers on to paper covered soil except in rainy or dull weather, as the higher temperature and lower humidity of the air and the fumes from the paper were harmful to newly set plants in sunny weather. With tarred paper injurious fumes are a very much more serious problem than with asphalt paper, and always appear to cause leaf scorch and to retard development (Anon., 1926 ; Böhnert, 1926 ; Eggert, 1926 ; Magruder, 1931b ; Weihenstephan, 1929). After unsuccessful preliminary trials with many crops tarred paper was written off as an unsuitable material for mulching.

A new soil-warming mulch material, black polyethylene plastic, has been found to force growth of melons and pickling cucumbers remarkably well, but no yield results are reported (Emmert, 1956a and b).

With regard to other types of mulch, Emerson (1903) found that the application of straw too early in the season before the soil had warmed up was harmful to the tender vine crops, but that growth of cucumbers was improved during dry periods by late strawing. In the hot climate of Israel, Griss (1949) reports that cucumbers and squash made more rapid growth under organic waste mulches, the foliage was greener, and the plants flowered earlier with more female flowers. He also noted that the growing season of cucumbers was extended by as much as 8-12 days. In Germany, too, cucumbers remained green longer under a cover of pine needles (Murawski, 1931). In Pennsylvania straw, manure, leaves, grass clippings and sawdust all resulted in more vigorous growth of cucumbers and the mulched plants were not checked during dry periods when the control plants wilted (Isenberg and Odland, 1950). Faster and greater vegetative growth has also been claimed as a result of covering the soil with aluminium foil (Wall, 1950) and glass (Weger, 1953). Thus a stimulation of growth appears to be a fairly general effect of mulching. Although different authors tend to stress different factors, such as nitrate supply, soil moisture, soil structure or temperature, as being responsible for this effect, these factors cannot really be considered in isolation as they are all to some extent interdependent. Growth is affected by the whole complex of

factors, and their relative importance must depend on environmental conditions.

The same applies to time of fruit production. For instance, low temperature or excessive vigour may retard cropping, water and nutrient supply may effect the rate of growth and the relative time of female flower production, and it is possible that flower production may also be influenced by intensity of radiation. It must be remembered that cucumbers are harvested immature whereas melons are left to ripen, so with the former crop temperature will be a rather less important factor in earliness than with the latter. In Montana and Missouri strawing retarded fruit production in cucumbers, squashes and pumpkins (Montana, 1915-1917; Rosa, 1923). In Nebraska also cucumbers and water melons were slightly later under straw mulch but, rather surprisingly, muskmelons were earlier (Emerson, 1903). In Leipzig cropping of cucumbers was very slightly advanced by strawing, though not significantly so (Bielka and Hildebrandt, 1954). It is interesting to note that in this German trial straw mulch delayed the harvesting of tomatoes. One can only guess at the reason for the difference in response of the two crops, but it seems possible that fruiting in cucumbers may be more closely related to vegetative growth than it is in tomatoes. In Israel, where mulches of straw, weeds, etc., stimulated vegetative growth and prolonged the growing season, they also advanced fruit production of cucumbers and squash by 5-8 days and extended the harvesting period of cucumbers by about three weeks (Griss, 1949). Paper mulching has in almost all cases favoured earliness of the vine crops, either by advancing the date of harvest (in one case of melons by as much as six weeks) or by increasing the early yield (Agassiz, B.C., 1931 ; Anon., 1926 ; Bassi, 1930 ; Becker, 1927 ; Böhnert, 1926 ; Boischot and Albert, 1931 ; Boresch, 1932 ; Canada, Div. Hort., 1930b, 1931 ; Diev, 1935 ; Edmond, 1929 ; Fredericton, N.B., 1930 ; Hutchins, 1931, 1933 ; Jensen, 1926 ; Lerch, 1930 ; Magruder, 1928, 1931a and b ; Moen, 1926 ; Morden, Man., 1930 ; Papworth, 1930 ; Reinhold and Schmidt, 1930a, 1933 ; Robb, 1929 ; Thompson and Platenius, 1932 ; Werner, 1933 ; Woods, 1937 ; v. Wrangell, 1929a).

The effect of light-reflecting mulches on earliness is not clear. Aluminium foil caused earlier fruit set in cucumbers and advanced fruiting in melons by two weeks (Wall, 1950). Covering the soil with Dutch lights, however, resulted in lower yields during the early part of the season, although the covered crop soon caught up with and overtook the controls (Weger, 1953).

On quality

Robb (1929) points out that earlier ripening of melons, which was obtained by paper mulching, also meant better quality. This is presumably because hot, dry conditions, which would favour

earliness, are needed for the development of the full flavour. This effect of paper mulching on quality of melons has not been mentioned by other authors. Larger fruits of melon and pumpkin have been obtained over paper (Canada, Div. Hort., 1930b ; Morden, Man., 1930 ; Reinhold and Schmidt, 1930a ; Summerland, B.C., 1931), but on straw mulch the fruits of muskmelon and water melon were smaller than those on the control plots (Emerson, 1903). Squashes grown on a mulch of cottonseed waste and straw in Israel gave a higher percentage of top grade fruit than the unmulched plants (Griss, 1949). The value of almost any type of mulch for keeping the fruit cleaner (Anon., 1926 ; Greenshields, 1830 ; Raymond [undated]) is self-evident.

In the case of cucumbers the term quality covers many points, such as shape, firmness, weight, flavour, cleanness, etc. It seems likely that at least shape and weight of the individual fruits may be related to the growth rate of the vines. Where a mulch of cottonseed waste and straw stimulated growth and prolonged the growing season in Israel, Griss found that the fruit was of better shape, firmer, less watery and sweeter ; there was also less soft fruit and a lower percentage of splits (Griss, 1949). In another trial Griss observed that more white fruit was produced on the uncovered plots than under straw mulch as a result of the higher temperatures. Bielka and Hildebrandt (1954), however, note that on irrigated sandy soil at Leipzig the quality of cucumbers was slightly lower, though not significantly so, on the strawed plots, although yields were higher. With Wega woodwool mulch it was found in one trial that there were more but much smaller fruits on the covered plots (Reinhold and Schmidt, 1933), in another that the shape and cleanness of the fruits was improved even though yields were not favourably affected (Reinhold, 1942), and in a third that both the number and average weight of individual fruits was increased (Bayer, 1951). Soil covers of peat and coke dust resulted in smaller fruits, while white sand gave slightly heavier but fewer fruits than the controls (Reinhold and Schmidt, 1933).

With aluminium foil Wall (1950) reports that the proportion of grade 1 cucumbers was very much higher on the covered plots and Weger (1951a) says that the average fruit weight was slightly higher. Covering the soil with Dutch lights also resulted in larger fruit (Weger, 1953).

The claims that have been made for paper mulching of cucumbers include better quality in general (Jensen, 1926 ; Magruder, 1928 ; Weihenstephan, 1929), higher average fruit weight (Becker, 1927 ; Magruder, 1931a ; Moen, 1926 ; Reinhold and Schmidt, 1930a, 1933 ; Weihenstephan 1929), better shape (Becker, 1927 ; Reinhold and Schmidt, 1933), and cleaner fruit (Magruder, 1928 ; Reinhold and Schmidt, 1933). In one trial in which paper mulching caused unhealthy growth, the mulched plants produced many deformed fruits (Langer, 1926).

On pests and diseases

The trailing habit of the vine crops and the contact of the fruit and foliage with the damp soil or moisture evaporating from it create a condition particularly favourable for the development of disease. A protective layer of mulch between the soil and the vines would clearly reduce the danger of infection, and the non-absorbent, impermeable mulches, such as aluminium foil, asphalt paper, plastic or glass, would give more effective protection than loose organic materials.

The prevention of fruit rot, by keeping the fruit off the soil, has been claimed as one of the advantages of mulching melons and squashes with organic materials (Anon., 1943 ; Blackie, 1955 ; U.S.D.A. Office of Information, 1945), aluminium foil (Wall, 1950) and plastic (Emmert, 1956a and b).

Seedbed mulching, however, appears to encourage damping-off. In a trial in Hawaii with cane bagasse it was found that cucumber seedlings coming up through the mulch needed thorough fungicide treatment to control the disease, which was favoured by the continually moist conditions at the soil surface (Gilbert, 1956).

Mildew appeared later in the season and was less severe on crops of cucumbers and squashes mulched with a mixture of cotton-seed waste and straw than on the cultivated crops (Griss, 1949). A cover of aluminium foil also reduced mildew infection on melons and cucumbers (Tiedjens, 1950 ; Wall, 1950). Although the organic mulch would be somewhat less effective than the foil in providing a dry layer for the vines and in reducing the relative humidity of the air, it did mean that there was less frequent need for irrigation and that the moisture supply in the soil was more constant. Both these factors would help to make conditions less favourable for the development of mildew.

A very early experiment on the effect of mulching on the amount of anthracnose infection in cucumbers showed that in a dry year a layer of hay slightly reduced the percentage of decay when the fruit was left in the field after cutting, but in a wet year neither hay nor woodwool mulches affected the prevalence of disease (New Jersey, 1896, 1897). In a recent trial on the use of Dutch lights as a soil cover under irrigated cucumbers, it was observed that the fruit had less anthracnose infection over the glass than over the uncovered soil (Weger, 1953). These findings suggest that a dry layer for the fruits to lie on is an advantage ; hay would be drier than soil except in a year of abundant rainfall, and glass would always dry off more quickly after rain.

Although dry air above the mulch layer can help to prevent certain diseases, it may have disadvantages. For instance, it was noticed in one trial that melon rust did more damage and spread more rapidly on plants mulched with asphalt paper (Canada, Div. Hort., 1930b). The reason for this was not given, but it may well have been due to the warmer and drier atmosphere over the paper.

In another trial red spider attack was more severe on paper mulched plants (Böhnert, 1926), presumably for the same reason.

Emerson (1903), in his straw mulching experiments in Nebraska, noticed that aphid injury was worse on the cultivated plots of cucumbers, muskmelons and water melons than on the strawed plots, both in dry and wet seasons. Again no reason is suggested, but it may be that vine growth was more rapid on the strawed plots, thus enabling the plants to grow away from the aphid injury better. Alternatively it might be due to a difference in the composition of the vines which determined the feeding preference of the aphids.

In Virginia the use of aluminium foil prevented damage from pickle worms on cucumbers and melons (Tiedjens, 1950 ; Wall, 1950). It is reported that in a two-years' experiment there was no pickle worm damage to melons on the foil plots although in one year the damage was as high as 65 per cent on the cultivated plots. It is thought that the protection may have been due, at least in part, to the glare from the shiny foil which might discourage the adult insects from alighting on the leaves.

The use of organic mulches to improve the growth of many crops, including cucurbits, on root-knot infested soil has been the subject of extensive study at the Florida Agricultural Experiment Station (Florida, 1938-1951 ; Watson, 1943, 1944). The investigations have been described in the section on Lettuce, but brief mention may be made here of the results obtained with cucurbits. It was found possible to grow cucumbers, melons and squash successfully on root-knot infested soil under a heavy organic mulch. It appeared at first that the type of material used made little difference to the growth of the plants provided it decayed rapidly and covered the ground well. Although the mulched plants had a larger number of knots on their roots, they had a higher proportion of healthy roots and showed a marked improvement in growth. Later it was found that squash plants mulched with forest leaves gave better yields than those mulched with miscellaneous vegetable material, such as dried grass and crotalaria stems, or than unmulched plants. On the other hand, nematode infestation was heaviest on the plants mulched with forest leaves. From the whole series of investigations it is concluded that mulching is ineffective for controlling the nematode but that it does enable the plants to grow better and produce higher yields on root-knot infested soil.

Economics

The work of Isenberg and Odland (1950) in Pennsylvania, which proved that all of five organic mulches (straw, manure, sawdust, leaves and grass clippings) were equally effective in increasing yields of cucumbers, shows that growers may safely use the cheapest and most readily available material. The authors consider that ' waste materials might be profitably used for mulching and the increased yield might more than pay for the costs of application '.

An example of the enterprising utilization of waste material is the use of a pine needle mulch in Germany which it is claimed gave very good results with cucumbers and was cheaper than peat (Murawski, 1931). This greatly simplifies the problem and suggests that organic mulching can be an economic practice provided conditions are such that the plants will benefit from a mulch. With cucurbits this is most likely to be the case under hot, dry or heavily irrigated conditions. Moreover, increased yields are not the only factor on the credit side of mulching. There is the saving in labour for weeding and cultivation (Emerson, 1903, and others) and possibly a saving of irrigation water. Griss (1949) calculated that the amount of irrigation water needed for cucumbers and squash in Israel was reduced by one-third to one-half by mulching with straw or other organic materials, and that total labour requirements were only 2-3 working days more per dunam ($\frac{1}{4}$ acre) on mulched plots. He also noted that after harvest the land under mulch was in much better condition and easier to prepare for the next crop. Crispin (1943) points out a further advantage with cucumbers, namely that strawing lengthens the growing season and so makes it possible to plant a few weeks earlier in some late districts of Israel such as the hot coastal zone. On a small acreage where irrigation is not possible, mulching may also be used as a cheaper and more convenient substitute (Rosa, 1923).

The cost of synthetic mulches, on the other hand, may be high, and larger returns will be needed than from waste organic materials for their use to be profitable. But cucumbers and melons are valuable crops and exacting in their requirements. As has been shown, they have responded very well to asphalt paper mulching, especially in the United States and Canada, and it is the general opinion there that these are among the few crops that can be paper mulched economically. In Europe, where the crop response has been more variable, opinions on the economic value of paper mulching have differed. Often the need for a cheaper, more durable paper has been stressed. Reinhold and Schmidt (1930a and b) made a detailed study of the costs and returns of mulching various crops with the relatively cheap Natronag paper. They found that on a moist, moorland soil, where paper could be used to best effect, mulched cucumbers gave the highest profit (770·8 RM per $\frac{1}{4}$ ha) of all the crops tested. Pumpkins, being a less valuable crop, only gave a profit of 114·9 RM per $\frac{1}{4}$ ha, although the yield increase due to mulching was not much less than that obtained with cucumbers. On a sandy soil, where paper was less effective, there was still a profit from mulched cucumbers, provided they were sown *in situ* and not transplanted, but it was considerably lower than on the moist soil. In a later study (Reinhold and Schmidt, 1933), in which Natronag paper was compared with the fertilized and more expensive Hallna paper, there was found to be little difference in the total yield of cucumbers as between the two types, and so the cheaper

paper proved the more economic. The use of fertilized paper is considered an expensive method of applying fertilizers.

Black polyethylene plastic, a new mulch material that has similar soil-warming properties to paper and which has shown considerable promise in preliminary trials, may prove to be a more economic proposition. It is more durable than paper, with an estimated life of four years, and is relatively cheap and easy to make. It is claimed that if a machine were developed to lay the plastic and set the plants or seeds through it its use would be more economical than that of any other mulch (Emmert, 1956b).

Conclusions

Experimental work on the mulching of cucurbits has been concerned mainly with the outdoor crops. Their trailing growth and their partiality for an open, well aerated but moist soil make them particularly responsive to suitable forms of mulching.

Organic mulches should only be used in warm climates and are more suitable for cucumbers than for melons. Provided the temperature is high enough, any type of organic mulch is likely to extend the growing season and increase yields, particularly under dry or heavily irrigated conditions. Earliness and quality may also be favourably affected, but these benefits are less certain. Strawing has reduced injury from aphids. Under suitable conditions the use of waste organic materials would very probably be an economic practice. Clover chaff has proved a suitable mulch for glasshouse cucumbers and does not cause nitrogen deficiency.

Cucumbers, muskmelons and water melons have almost always responded favourably to asphalt paper mulching with increased yields and earliness and often with better quality. The few exceptions have generally been under cold or wet conditions. Transplanting cucumbers onto paper mulched land during sunny, dry weather, however, is not recommended. The use of paper has made it possible to extend the range of melon culture to cooler areas where production had previously been considered impossible. There is a danger of red spider attack and melon rust being more severe over paper. Cucumbers and melons are among the few crops for which the expensive practice of paper mulching has generally been considered economic. It is most likely to be profitable on moist soils in warm, dry seasons. Preliminary trials suggest that black plastic may prove a cheaper substitute for paper.

Aluminium foil is a promising mulch material for the vine crops, which appear to respond well to increased radiation. The use of foil has prevented damage from pickle worm and reduced mildew infection.

The use of Dutch lights as a soil cover has also given very good results with cucumbers, both by maintaining the structure of the soil and by increasing radiation. The commercial possibilities of this seemingly expensive practice have not been studied.

CHAPTER 5

GLOBE ARTICHOKES

In severe winters globe artichokes are liable to suffer from frost damage unless protected, and in England, especially in the North, it is quite a common practice either to earth up the crowns or to cover them with some form of litter, or both. This winter mulching is an old English custom and was advocated by Philip Miller in his *Gardener's Kalendar* of 1757 and his *Gardener's Dictionary* of 1759. The system recommended by Miller is to ridge the artichoke crowns in November, and later, if there is danger of severe frost, to cover the ridges with straw, long dung, pea haulm or tanner's bark. This ensures that the mulch does not come in direct contact with the roots. He condemns the system of laying fresh manure directly over the roots, " as is by some unskilful persons too often practised ", because it is apt to cause rotting or " renders the plants hard and woody in the spring, and causes them to produce small and ill-nourished heads ". There seems to have been some difference of opinion on this point, however, for some years later Nicol (cited Loudon, 1835) mentions that " the strongest crowns he ever saw . . . were generally covered before winter with a mixture of stable litter and seaweed ".

The old custom of winter mulching, either with or without earthing up, has persisted in England (Hoare, 1949 ; Oldham, 1950 ; Robinson, 1920) ; dry leaves, straw, litter, bracken or ashes are commonly used. In southern Europe and North Africa, where the globe artichoke is most extensively grown, the winters are sufficiently mild for no protection to be needed. In the United States commercial production is limited to California and certain other warm districts, where again no winter protection is given, but gardeners who wish to grow artichokes in the more northern States are recommended to heap about a foot of coal ashes or washed cinders over the crowns during the frost period (Brown and Hutchison, 1949 ; Knott, 1949). Knott, like Miller, states that manure is unsatisfactory as a protecting medium as it seems to favour rotting.

In the large producing centres the crops are generally irrigated and summer mulching is not used as a moisture conserving measure. In England, however, where artichokes are grown mainly as a garden crop, it is quite a common practice. Robinson (1920) recommends giving a good mulch of half rotten manure after watering, and adds: " When grown on poor or dry soils, the effect of covering the soil with light manure, lawn mowings, or any such

material that can be spared is excellent. In rich, moist soils it is not wanted, except in very dry seasons."

Summer mulching with asphalt paper also gave very promising results in preliminary trials on the Continent. v. Wrangell (1929a and b), working at Hohenheim on heavy loam soil, planted seedling artichokes through holes in Bitumitekt, asphalt-impregnated paper. The test season was very hot and dry. Although high yields can never be expected from first year plants, the use of paper increased yields by an average of 175 per cent. On unmanured plots the mulched plants produced 2·1 kg./10m^2, compared with 0·5 kg. for the controls, while on manured plots the figures were 1·2 and 0·7 kg. respectively. The mulch stimulated growth and made it possible to harvest the heads earlier. Paper mulch trials in Czechoslovakia (Boresch, 1932) on sandy loam soil gave similar good results with first year Green French artichokes. On the mulched plot 18 heads were harvested compared with 12 on the controls, and the average yield was 4·04 kg. compared with 1·94. Unfortunately no work is reported on the effect of paper mulching on the crops produced in subsequent years. These preliminary trials, however, suggest that a heat-absorbing mulch such as black paper may make it easier to produce this heat-loving crop in cool climates.

CHAPTER 6

LETTUCE AND ENDIVE

General

Lettuce and endive are difficult crops to mulch, growing as they do close to the ground and requiring free movement of air round the collar to prevent fungus infection. Coarse organic materials such as straw and litter, although they would provide the moist conditions and cool root run which are desirable for these crops, are too bulky to use conveniently. Emerson (1903) and Werner (1933), moreover, who have made extensive studies of mulching with various plants in Nebraska, consider that the practice is of doubtful value for such short season crops, especially for leaf lettuce which is an early crop harvested before the serious drought period in July-August. They now appear to be used only for specific purposes, such as to reduce root-knot damage or manganese toxicity.

In recent years sawdust has been used both experimentally and commercially on lettuce with very promising results. It has the advantage of being less bulky than straw or manure while at the same time it keeps the soil moist and cool. A grower in New Zealand (Lyndon, 1947) who grows all his vegetables, including lettuce, under a shallow mulch of sawdust (mainly *Pinus insignis*) claims that soil conditions are thereby improved, weed growth is suppressed and the labour of watering reduced. He recommends that lettuce seed should be covered with 1 inch of sawdust which is firmed with a spade and given a dressing of lime to counteract acidity. A grower in England (Horsey, 1950) has also had good results from raising lettuce in frames under a sawdust mulch. In this case hardwood sawdust was used, the seed sown thinly on the soil surface and covered with only $\frac{1}{4}$ inch of sawdust. Germination was excellent and the plants produced a vigorous root system with a clear $\frac{1}{2}$ inch collar which allowed shallow planting and seemed to prevent botrytis. Trials in British Columbia have also shown the value of sawdust mulching for lettuce, provided the seed is sown on the soil surface and covered with 1 inch of sawdust, not sown directly into a deeper mulch (Woods, 1951).

Although work on organic mulches for lettuce has been very limited, the value of paper mulch has been fairly widely tested. Results, however, have been variable. In many cases experimental data on soil and weather conditions are insufficient to allow any conclusions to be drawn. It does appear, however, that on moisture-retaining soils a paper mulch makes it possible to grow lettuce during a drought season when unmulched crops would fail (Bassi, 1930 ; Morden, Man., 1930). Under tropical conditions, moreover,

the use of white paper has improved the growth of temperate vegetables such as head lettuce by reducing soil temperatures (Sherman *et al.*, 1953).

Aluminium foil, being a thin, clean material with moisture-conserving and temperature-reducing properties, seemed an ideal mulch material for lettuce when it was first experimented with (Tiedjens, 1950 ; Wall, 1950). Later, however, it was found that plants mulched with foil were very liable to attack by *Fusarium* slime rot (Burgis, 1951 ; Florida, 1951). This serious disadvantage may possibly be overcome by treating the foil with copper (Florida, 1951) but the position is not yet clear. The price of aluminium foil, moreover, limits its use commercially.

Effects of Mulching

On yield

The first experimental results available on the straw mulching of lettuce or endive come from Montana (Montana, 1915, 1917). No yield data are given but in one test cultivation gave better results than mulching with both crops, it being suggested that straw reduced soil temperatures too much, while in another trial straw slightly increased the yield of endive which appeared to benefit from the cooler soil. It is reported from Nebraska that straw mulching showed promise as a means of growing head lettuce in that hot climate (Nebraska, 1935), but again no details are given.

A summer mulch of cow manure was found to be beneficial to lettuce at Hawkesbury Agricultural College, N.S.W., giving good yields of high quality heads (Waring, 1950).

Sawdust mulching in British Columbia improved yields of Great Lakes lettuce sown in June (Woods, 1951). Being a rapidly maturing crop the lettuce was not affected by the nitrogen depression caused by the sawdust, which first appeared on other test crops in mid-August. Increased yields were also obtained from sawdust mulching in New South Wales, but serious nitrogen deficiency occurred when the mulch was ploughed in (Waring, 1950).

Spectacular results have been obtained from mulching on certain red, highly manganiferous soils in Hawaii which had previously been considered unsuitable for crop production. It was found that by reducing the soil temperature and preventing drying out mulches produced a condition more favourable for the hydration of manganese oxides and thus prevented Mn toxicity. Various materials have been tested as mulches and all were beneficial. Board slats gave a 5-fold increase in lettuce yields and prevented the appearance of " yellow leaf fringe " (Sherman and Fujimoto, 1947). A white paper mulch which reflects radiant heat greatly improved the growth of head lettuce (Sherman *et al.*, 1953), and organic mulches have given a marked increase in yield with a considerable decrease of bottom rot (Foster, 1953).

The first paper mulching trials with lettuce were carried out in 1927 in Virginia, U.S.A., on a loamy soil (Flint, 1928). On a weight per stalk basis yields were more than doubled as a result of mulching, but as the weather conditions are not recorded these results are not much help in determining when and where paper will be beneficial. Other results from America are less favourable but equally inconclusive. In Michigan paper had no effect on yields of seeded lettuce in a wet season (Edmond, 1929). In Ohio in a season with adequate rainfall early seeded lettuce was adversely affected by paper mulching, black paper reducing yields by 4 per cent and light-coloured paper by 15 per cent (Magruder, 1930). Lettuce grown from plants, however, showed a 28 per cent increase from black paper and a 49 per cent increase from light paper in the same trial. No explanation is given to account for the difference in responses of the seeded and planted crops, nor for the fact that the same yield trends were produced by the temperature-increasing black paper and the temperature-reducing light paper. In this case the moisture-conserving action of the mulch can be disregarded as rainfall was adequate. In an experiment with leaf lettuce in a drought season in Ohio, paper mulching increased yields by 227 per cent (Magruder, 1931b), whereas in a normal season in Minnesota the increase was only 47 per cent (Hutchins, 1933). The results of Canadian trials are also inconclusive (Agassiz, B.C., 1930, 1931 ; Canada, Div. Hort., 1930b, 1931, 1936 ; Fredericton, N.B., 1930 ; Kapuskasing, Ont., 1930 ; La Ferme, Quebec, 1931 ; Morden, Man., 1930, 1938 ; Summerland, B.C., 1930 ; Woods, 1937). In many cases the effect of paper mulching was small or insignificant. In only two trials was a marked increase in yield obtained, once in a very dry season and once in a hot, wet season. Lack of information on soil conditions makes interpretation impossible.

In France yield increases due to paper mulching were obtained in only 1 out of 3 trials (de Marcillac, 1930 ; Boischot and Albert, 1931 ; Labrousse quoted Servy, 1933). In Germany the German Natronag paper was tested with spring-sown lettuce on a humus sandy soil in an exceptionally wet season (Reinhold and Schmidt, 1933). Yields were increased by 25·5 per cent, possibly as a result of the higher temperatures and better soil conditions due to protection of the soil from heavy rain. In Italy paper mulching was used in a year of severe drought with striking results (Bassi, 1930). Autumn-sown lettuce mulched in March gave an increase of 25 per cent over the unmulched crop, while in another area spring-sown lettuce mulched at the time of sowing yielded five times as much as the controls and was followed by a second crop planted in August which yielded three times as much as the controls. These outstanding results appear to be due to the exceptional drought conditions which, at least in one case, prevented the control plants from forming heads. It is significant that the soil in both cases was clay and therefore moisture-retaining. Mulching would thus conserve the

moisture that was already present in the soil and prevent baking. In a more freely-draining soil the mulch might not have been so effective under conditions of severe drought.

Aluminium foil gave spectacular results when it was first tested in Virginia (Tiedjens, 1950 ; Wall, 1950). Yields of mulched head lettuce were 2-4 times those of the controls, while yields of leaf lettuce were increased by 60 per cent. With endive ' phenomenal ' increases are reported. A test in Florida failed because of slime rot infection which was most severe on the mulched plots (Burgis, 1951).

Vermiculite has been tested on many vegetable crops at the Arizona Experiment Station as a mulch $\frac{1}{2}$ inch deep and 1 inch wide over the seed row. Under those conditions of high temperature and low humidity it had a strikingly good effect due largely to its insulating and moisture-holding properties. Yields of autumn head lettuce were increased by 23 per cent and head size was improved (Anon., 1954 ; Siciliano, 1955).

On growth and maturity

When small seed, such as lettuce, was sown directly into a 2-inch mulch of sawdust at the normal depth it failed to emerge evenly owing to drying out of the sawdust (Woods, 1951). It was found, however, that excellent germination could be obtained by drawing a drill in the sawdust down to soil level, sowing the seed on the soil surface and replacing 1 inch of sawdust. Excellent germination of lettuce in frames has also been obtained by sowing the seed on the soil surface and covering with $\frac{1}{4}$ inch of sawdust (Horsey, 1950). There is no information on the effect of paper mulching on lettuce germination. Leaf lettuce mulched with aluminium foil germinated two days earlier than the controls and the stand was thicker (Wall, 1950). Vermiculite applied over the seed rows resulted in quicker and more even germination in Arizona and increased the stand by 135 per cent (Anon., 1954 ; Siciliano, 1955).

There are several reports of more vigorous early growth and larger heads as a result of mulching with paper (Bassi, 1930 ; Magruder, 1930 ; Morden, Man., 1930 ; Mutzek, 1926 ; Werner, 1933) and aluminium foil (Wall, 1950). Improved moisture conditions are presumably largely responsible for this. A temperature effect may also be involved, but since light-coloured paper and foil tend to reduce soil temperature and black paper to increase it the relationship is not a simple one. Lettuce varieties vary greatly in their temperature requirements, so variety as well as mulch material, weather and date of sowing would have to be considered in evaluating a temperature effect.

This interaction of a number of factors may also be responsible for the apparently contradictory results that have been obtained concerning the effect of mulching on time of maturity. Tests in

British Columbia showed that maturity of June-sown lettuce was advanced by a sawdust mulch, although warm season crops were retarded owing to the cooler soil conditions (Woods, 1951). With aluminium foil also, maturity was two weeks earlier (Wall, 1950). In a test with May-sown lettuce in Ohio light-coloured paper retarded and black paper advanced maturity (Magruder, 1930). Several other workers note that black paper mulch resulted in increased earliness (Bassi, 1930; Canada, Div. Hort., 1930b; Morden, Man., 1930; La Ferme, Quebec, 1931; Woods, 1937). It would clearly be unwise to base practical conclusions on such contradictory and empirical results.

On quality

In very dry years when conditions were such that unmulched lettuce failed to form heads, paper mulching made it possible for the plants to head up normally and produce a good crop (Bassi, 1930; Morden, Man., 1930). This would presumably only happen if the soil were well supplied with water from below so that the moisture-conserving action of the mulch could come into full play. Initially dry or porous soil could account for failures, such as that reported by Magruder (1930). In this case the whole of a late lettuce crop bolted during a drought period in September, the mulched portion bolting first. It appears that here moisture conditions were not improved sufficiently to counterbalance the detrimental effects of high temperature induced by paper mulching. The higher temperatures obtained with black paper are certainly a danger to lettuce under some conditions. In the Mediterranean district of France, for instance, mulched lettuce was rapidly scorched by the heat reflected from the paper (Boischot and Albert, 1931).

Under less extreme conditions paper mulching has had a variable effect on quality. In a German trial a higher proportion of good heads was produced (Reinhold and Schmidt, 1933). Flint (1928) and Hutchins (1933) in America also report that mulched lettuce made heavier heads, but Magruder (1930) records that although the heads were larger they were less solid and there were more double heads as a result of the more rapid growth. In a Canadian trial the unmulched lettuce was heavier and firmer (Canada, Div. Hort., 1930b).

In a comparison of paper and straw mulching in Nebraska, the paper mulched plants were larger but formed no good heads, whereas under straw some very good heads were formed on small plants (Werner, 1933).

In a single trial in Virginia aluminium foil mulch resulted in larger, firmer and crisper heads (Wall, 1950).

On pests and diseases

The root-knot nematode, *Heterodera marioni*, is one of the most serious horticultural pests on sandy soils in the southern

states of the U.S.A. A very wide range of plants is susceptible to attack, lettuce being among them. A heavy mulch of decaying vegetable material has long been advocated for perennial plants grown in infested soil, but it is only comparatively recently that the action of the mulch has been scientifically investigated and the practice extended to annual vegetable crops. The investigations were started in 1938 at the Florida Agricultural Experiment Station and were continued until 1951 (Florida, 1938-1951 ; Watson, 1943, 1944). As lettuce was one of the test crops used, a brief summary of the findings will be of interest here. Dead grass, leaves or weeds proved excellent mulch material, especially when a covering of Spanish moss was used to prevent them from blowing away and drying out. Water hyacinths were found to be particularly suitable material as they hold water for a long time. The method recommended for annual crops was to apply a deep mulch in windrows with a narrow strip of uncovered soil between them in which to sow the seed or set the plants. In one experiment with winter lettuce mulched with various materials, including dried grass, crotalaria stems, leaf mould and water hyacinths, the mulched plants made much better growth than the controls and showed a lighter infestation of root-knot (Florida, 1941). In another experiment lettuce grown on a plot to which mulch had been applied the previous year and then removed was decidedly better and less heavily infested than lettuce grown on a plot that had not previously been mulched, thus showing that nematode injury was retarded by at least six months by mulching (Florida, 1942). In a trial to determine the effects of different types and depths of mulch it was found that type of material made very little difference provided it decayed rapidly and covered the ground well. Lettuce made better growth on all the mulched plots than on the controls, the benefit increasing with the depth of mulch (Florida, 1944). Paper mulch, however, has not been successful in improving growth on nematode-infested soil (Watson, 1944). It was thought at first that the beneficial action of mulch might be due to the destruction of the nematodes by fungi living in the decaying vegetable matter. Later experiments, however, showed that in general the roots of mulched plants had nearly as many knots as the controls, although the mulched plants had a greater number of healthy roots. It is concluded that mulches are, in fact, ineffective for nematode control, and that their beneficial effect on growth and yield in nematode-infested soil is due to the better moisture conditions and liberation of nutrients. Presumably the improved conditions enable the plants to continue producing new roots in spite of root-knot infestation. In view of the fact that mulch does not provide control of the nematodes and is, moreover, difficult and clumsy to use on lettuce, the use of soil sterilants appears to be a more promising line of approach to the problem of growing this crop on infested land.

Another interesting though less detailed investigation on the

use of organic mulches to prevent infection of lettuce was concerned with the damping-off diseases, *Rhizoctonia* and *Sclerotinia* (Green and Waid, 1907). Forced lettuce grown in glasshouses in Ohio frequently gave very poor crops, and it had been reported that the drying out and baking of the soil during the hot summer months when it was not in use had detrimental effects on lettuce yields and increased *Rhizoctonia* and *Sclerotinia* activity. In a trial at the Ohio Agricultural Experiment Station a mulch of strawy manure was spread over the beds to a depth of 5-6 inches during August and early September when the houses were not in cropping. The mulch was watered frequently enough to keep the soil moist and leach the nutrients out of the manure. At planting time in mid-September the coarse part of the manure was removed and the fine portion worked in. It was found that by this means three successive crops of lettuce could be raised without further addition of manure or fertilizers. Very favourable results were obtained both in this experiment and in similar independent trials carried out by a commercial firm in Ohio. No attempt was made specifically to study the effect of the mulch on lettuce diseases but the crops were reported to be practically free from disease. It is suggested that by keeping the soil moist the damping-off fungi might be prevented from going into the resting stage and hence from becoming more active when the soil was moistened again at planting time. More evidence is needed to confirm this theory but the practice deserves consideration in districts where baking of glasshouse soils is a problem.

Mulching with fresh cane bagasse in Hawaii resulted in a reduction in the amount of *Rhizoctonia* bottom rot in transplanted lettuce given overhead irrigation, but with furrow irrigation this was not the case (Gilbert, 1956). As the bagasse tended to clog the furrows and cause flooding, it is suggested that the fungus inoculum may have been spread by the water. The cane bagasse had no effect on incidence of tipburn.

No experimental work has been done on the health of lettuce grown on sawdust mulch, but an English grower who covered his seed in frames with a $\frac{1}{4}$-inch layer of hardwood sawdust mentions that the good aeration round the collar of the seedlings seemed to prevent botrytis (Horsey, 1950). In a trial comparing the growth of vegetables on dug and undug soil, part of each treatment being mulched with sawdust, it was noticed that surface cutworms only attacked lettuce on the undug, mulched plots (Chase, 1952).

Aluminium foil mulch, which at first gave exceptionally promising results with lettuce, was soon found to favour the development of *Fusarium*. Preliminary tests with lettuce at the Vegetable Crops Laboratory, Florida, failed because of slime rot infection which attacked the plants as they approached maturity. Although all the plots were affected the infection was most severe on those covered with foil (Burgis, 1951). An attempt was made

by the Florida Agricultural Experiment Station to overcome this difficulty by painting the paper side of paper-backed foil with a copper paste to inhibit the growth of *Fusarium* (Florida, 1951). Cold weather nullified the effect of the mulch, the yield of lettuce being significantly better on the control plots. Coating the foil with copper, however, gave very good control of *Fusarium* and in this respect the copper-treated foil plots were as good as the controls and significantly better than the non-treated foil plots. Further experiments are needed before foil mulch can definitely be recommended for lettuce, and it also remains to be seen whether copper treatment will excessively increase the cost of this already expensive material.

Evidence on the effect of paper mulch on lettuce diseases is limited to a couple of observations. In a test in Ohio paper mulching had no effect on tipburn or soft rot of early head lettuce (Magruder, 1930). In a French trial the presence of stagnant water on the paper created an atmosphere very favourable to the development of downy mildew, *Bremia lactucae*, on cabbage lettuce (Labrousse, quoted Servy, 1933).

Economics

As lettuce is neither a heat-loving nor a very high value crop it is doubtful whether the use of paper mulching would normally be economic. The results have been too variable to justify the risk on such a high outlay. From experience in British Columbia Woods (1937) concludes that the slight increases in yield and earliness are not sufficient to cover the cost of material and labour. Magruder (1930) points out that where row crops are closely spaced there is not room to anchor the paper with soil, and the cost of labour for anchoring it by other methods is too high to be economic. This disadvantage would apply to seeded lettuce but not necessarily to planted lettuce, as the plants can be set through holes in the paper. In favour of paper mulching, however, Bassi (1930) mentions that several crops can be grown in succession without intermediate cultivation as the soil under paper is maintained in excellent condition. He suggests several rotations, including lettuce and endive, in which no cultivation is needed between harvesting and planting.

The cost of aluminium foil is high, and it remains to be seen whether the manufacture of copper-treated foil suitable for lettuce will be considered economic.

Sawdust is cheap and readily available in many districts and shows promise of being a very suitable mulch for lettuce.

Vermiculite would clearly be too expensive to use as a complete surface mulch but when used as a cover over the seed rows it has given promising results in the arid climate of Arizona. From trials there it was concluded that "applied properly it cuts costs by reducing water requirements" (Anon., 1954).

Conclusions

Bulky organic mulches are difficult to use on lettuce and little work has been done on them. They improve growth on root-knot infested or highly manganiferous soils. Covering glasshouse soils with strawy manure to prevent them drying out when not in use appears to benefit the subsequent lettuce crops.

Sawdust mulches have been tested recently with very promising results.

Paper mulching has given variable results as regards both yield and quality. It is most likely to be of benefit in a drought season on a moisture-retaining soil. The uncertain results and high cost make it of doubtful value.

Aluminium foil mulch has given excellent results with lettuce and endive but cannot at present be recommended as it favours development of *Fusarium*. The cost is high and its economic value has not been studied.

CHAPTER 7

ONIONS AND LEEKS

General

Straw and other forms of litter have many disadvantages as mulch materials for onions. They shade the bulbs from the sun and so delay ripening ; they are difficult to apply over the young plants without causing injury ; and they reduce soil temperatures. Some varieties of onion need relatively high temperatures for bulb formation, and will run to seed in cooler conditions, especially during short days. Only under very warm, dry conditions is field mulching considered beneficial. For all these reasons asphalt paper, which is thin and tends to increase soil temperatures, would seem to be a more suitable form of mulch material for this crop. Paper mulch, however, is so expensive that consistently large increases in yield would be needed to justify its use, and, as will be shown later, this has not been the case with onions.

Since leeks are either planted deeply or earthed up to blanch the stems, root growth during the later part of the season occurs at a depth where soil conditions would not be greatly affected by surface mulching. They are therefore a crop that would be unlikely to respond to any great extent. Probably for this reason very few mulching experiments have been concerned with leeks.

Effects of Mulching

On yield

Even in the hot state of Nebraska where summer droughts are common, straw mulching has not generally been of much benefit to onions. Emerson (1903) used a mulch of old straw, 4 inches deep when settled, on various soils over a period of three years. With drilled onions, mulched two months after sowing, there was no effect on yield, but when the straw was applied earlier many plants were killed during the process of spreading and yields were reduced. Yields of transplanted onions, strawed 3-4 weeks after planting, were also unaffected. In a later trial Werner (1933) used a cover of new wheat straw, 2-4 inches deep when settled. In one year there was again very little response, but in the following year which was exceptionally hot and dry yields of unirrigated onions were increased by 78 per cent. Irrigated onions only gave an increase of 26 per cent as a result of strawing, which suggests that the better moisture supply under straw was largely responsible for the good

effect. This is confirmed by the fact that yields of mulched crops grown without irrigation were about equal to those of unmulched irrigated crops.

In the cooler climate of Montana, with good seasonal rainfall, onions did better under normal cultivation than under straw (Montana, 1915-1917). At Geisenheim in Germany, where a 10 cm. layer of hay was used and the crop irrigated, there was also no benefit from mulching (Geisenheim, 1954). No details are reported for either trial.

In Rhodesia it is claimed that mulching is of considerable benefit to the onion crop and saves irrigation water (Hayter, 1950). It is recommended to place long grass between the rows as planting proceeds or to use short materials such as groundnut shells, sawdust, wood shavings or compost. In South Africa a thin layer of well-rotted stable manure is recommended on sandy soil to supply nutrients, keep the soil cooler and conserve moisture (Smith, 1937). It is claimed that such a mulch will result in a great increase in size of bulbs and total weight of crop. No experimental work appears to have been reported from these countries.

Sawdust mulching gave poor results with onions in British Columbia (Woods, 1951) and its use on this warm season crop is not recommended by the Agassiz Experimental Farm (Fletcher *et al.*, 1952). In Hawaii, however, onions have made very strong growth under sawdust (Swanson, 1953).

The effect of paper mulching on onion yields has been extremely variable and it is difficult to account for the results obtained. Sometimes paper mulched crops have produced considerably higher yields than the controls (Böhnert, 1926 ; Diev, 1935 ; Magruder, 1931b ; Morden, Man., 1930, 1938 ; Otto, 1926 ; Saunders, 1954 ; Tacke, 1928) ; sometimes they have produced only half as much as the unmulched crops or even less (Hutchins, 1933 ; Kapuskasing, Ont., 1930 ; Summerland, B.C., 1930) ; and often the treatment has made little if any difference to yield (Agassiz, B.C., 1930, 1931 ; Canada, Div. Hort., 1930b ; Magruder, 1929, 1930 ; Woods, 1937). There seems to be no consistent relationship between the effect on yield and weather conditions, soil or method of culture. In one trial in Germany, for instance, the seeded crop responded very much better than the transplanted one (Tacke, 1928), whereas in Ohio the seeded crop responded unfavourably to paper mulching and the transplanted crop was unaffected (Magruder, 1930). In the former trial only white paper was beneficial, black paper scorching the crop, whereas in the latter trial higher yields were obtained with black than with light-coloured paper.

Aluminium foil was tested on onions at the Florida Agricultural Experiment Station with the result that yields were increased by 315 per cent (Burgis, 1951 ; Florida, 1950). Differential fertilizer treatments showed that this yield response was directly related to the conservation of fertilizer by the foil. It is also suggested,

though without evidence, that the benefit may have been partly due to the reduction of soil temperature.

Very little work has been done on the mulching of leeks. Hayter (1955) reports that the crop has been mulched with sawdust in Southern Rhodesia with significant results, but no details are given.

In one paper mulch trial in Minnesota, when onion yields were considerably reduced by mulching, the yield of leeks was increased by 23 per cent (Hutchins, 1933). The reason for this is not apparent, but it may be that leeks need a better supply of moisture than onions. In Germany, too, paper mulching was of some small advantage to leeks, the yield increase being 7 per cent on harrowed soil and 20 per cent on the drier, ploughed soil (Reinhold and Schmidt, 1930a).

On growth and maturity

Seedbed mulching appears to be a fairly common practice in some tropical countries to improve conditions for germination by protecting the beds from the sun and conserving moisture. In Rhodesia and South Africa grass is used (Hayter, 1950 ; Marshall, 1932 ; Vorster, 1951), in parts of Burma straw and plantain leaves (Ba Maung, 1936) and in Jamaica trash (Spooner, 1930). Generally it is recommended to remove the mulch as soon as the seedlings appear, since, if it is left on too long, the plants will become spindly and more liable to damping-off (Marshall, 1932). Hayter (1950), however, says that the grass mulch may be left on the beds if it has been spread in the same direction as the seed rows, as the plants will be able to push their way through it.

It has been found in British Columbia that emergence of onion and other small seed will be very uneven if the seed is sown directly into a 2-inch layer of sawdust mulch, owing to the drying out of the sawdust (Woods, 1951). The method recommended is to sow the seed on the soil surface and then replace 1 inch of sawdust. A grower in New Zealand has also obtained good results from sowing onion and leek seed on the soil surface and covering with a sawdust mulch, but he used a 2-inch cover (Lyndon, 1947). Germination of onion seed has sometimes been stimulated by paper mulching (Canada, Div. Hort., 1931 ; Werner, 1933), but Hutchins (1933) found that the rate of emergence was unaffected.

It is difficult to straw drilled onions in the seedling stage without injuring the plants. Emerson (1903) found that many plants were killed by too early strawing, within two months of sowing. A straw mulch will also tend to reduce the early growth of the plants (Werner, 1933) and retard maturity (Montana, 1915-1917) as a result of the lower temperature and nitrate content of the soil. Musso (1932), however, claims that roots will develop more rapidly on transplanted onions if they are mulched with straw, manure or leaves, as a large difference between soil and air temperatures

in the daytime favours root formation. In some trials paper mulching stimulated the early growth of onions (Canada, Div. Hort., 1930b, 1931 ; Werner, 1933), while in others there was no difference in vigour (Florida, 1930 ; Magruder, 1930). The early growth of leeks was unaffected by paper mulching (Boischot, 1930). The effect of paper on maturity of onions has also been inconsistent ; Woods (1937) reports that the crop was slightly earlier, whereas Boischot and Albert (1931) found there was no difference in earliness.

As with many other crops, tarred or other unsuitable forms of mulch paper have caused injury to onion plants (Anon., 1926 ; Magruder, 1931b ; Tacke, 1928).

On quality

Only very general and inadequate information is available on the quality of mulched onions. In his extensive mulching experiments in Nebraska, Werner (1933) found that the quality of all the vegetables tested, and these included onions, was better with straw than with paper mulch. Paper mulching, however, did increase the percentage of prime onions, compared with normal cultivation, complete coverage of the soil giving better quality than partial coverage. In tests in Ohio, on the other hand, transplanted onions showed little if any difference in grade as a result of paper mulching, and mulched drilled onions had a slightly lower percentage of No. 1 grade bulbs (Magruder, 1930). Larger bulbs were obtained with paper mulch in France (Boischot and Albert, 1931), but a very much higher proportion of small bulbs, due to overcrowding, in New Brunswick (Fredericton, N.B., 1930).

An advocate of crushed corncobs as a soil cover (Merritt, 1943) mentions that spring onions grown under such a mulch proved most succulent and mild.

No work appears to have been done on the effect of mulching on storage quality of onions.

On pests and diseases

As the onion fly lays its eggs either on the base of the plant or in the soil near it, one might expect a soil cover to discourage egg laying and reduce the amount of infestation. Trials have shown, however, that this is not so with paper mulching. In one test in Canada (Canada, Div. Hort., 1931), where there was a serious infestation of onion fly, it is reported that mulch paper did not inhibit the activity of the maggot in the least. In another Canadian test (Summerland, B.C., 1931) onion maggot destroyed the whole crop, the damage being 100 per cent with the paper and 80-90 per cent where no paper was used. The thin layer of paper, however, leaves the base of the bulbs exposed and a narrow strip of uncovered soil is left along the plant rows. A bulky organic mulch might thus give more effective protection, but there is no information on this point.

Robb (1929) mentions that in a paper mulching trial at Vineland, Ontario, attack by onion thrips was much worse on one of the mulched plots than on the controls. This may have been due to the warmer, drier air over the paper.

Economics

Owing to the difficulty of applying straw mulch without damaging the plants, Emerson (1903) considers that the practice of strawing is undesirable for seeded onions. Werner (1933) found that the same difficulty applied to transplanted onions and that it more than offset any advantage that strawing might have in a very dry season. He also points out that seeded onions are an early, short season crop in Nebraska and are therefore unlikely to benefit greatly from strawing.

It is generally considered that paper mulching will only be economic if used on a high value crop that responds with considerably increased yields and earliness. Onions are not a particularly valuable crop, and although they have occasionally given much higher yields as a result of paper mulching their response has been very variable. Boischot and Albert (1931) worked out the cost of paper mulching onions in France, and found that it was higher than the cost of irrigation. They conclude that paper mulching would not be economic even in the Mediterranean district, where drought periods are likely to be longer than in other parts of France. Costs and returns were also calculated in Russia (Diev, 1935) where the practice proved uneconomic in spite of increased yields.

A careful study of the economics of paper mulching was made on a large number of crops in Germany by Reinhold and Schmidt (1930a and b). Onions were not included, but leeks were grown as an inter-crop with cucumbers and kohlrabi. The initial cost of the paper was therefore shared between the three crops. By using this rotation mulched leeks did show a slightly larger profit than the cultivated crop, even though the yield was only increased by 20 per cent. This was only the case, however, on a ploughed sandy soil ; on the same soil which had been harrowed and was therefore moister, the yield increase was smaller and paper mulching did not prove profitable. From these results it is clear that even when the same paper is used for several crops the margin of profit with leeks is very small.

Conclusions

Straw or hay mulching cannot be generally recommended for onions. It is not likely to be of benefit except in a very hot, dry climate ; it is difficult to avoid damage to the plants during application ; and ripening of the bulbs may be delayed. Strawing does not appear to have been tested on leeks. Seedbed mulching with grass or other litter appears to be a beneficial practice under tropical conditions.

The scanty information available on sawdust mulching suggests that this is also an unsuitable practice for onions, at least under British Columbia conditions.

Paper mulching has given highly variable results with onions. No consistent effects can be traced on either yield, growth, time of ripening or quality. The use of paper does not reduce onion fly damage and may encourage thrips. It is not likely to be an economic practice.

Leeks may be benefited to a small extent by paper mulching.

A single test indicates that aluminium foil is a promising mulch material for onions, the benefit being directly related to the conservation of fertilizers.

CHAPTER 8

PEAS AND BEANS

General

The practice of mulching legumes appears to be a very old one in England, although it is difficult to tell when it became established. It seems to have been used first as a method of frost protection. Philip Miller, "Gardener to the Worshipful Company of Apothecaries, at their Botanick Garden in Chelsea", makes repeated mention of it in his *Gardeners Dictionary* of 1759. For autumn-sown broad beans he recommends that: "as soon as they are two Inches above Ground, the Earth should be carefully drawn up with a Hoe to their Stems, and this must be two or three Times repeated, as the Beans advance in Height ; this will protect their Stems from the Frost, and encourage their Strength. If the winter should prove severe, it will be very proper to cover the Beans with Peas Haulm, Fern, or some other light covering, which will secure them from the Injury of Frost ; but this covering must be constantly taken off in mild Weather, otherwise the Beans will draw up tall and weak, and come to little ; and if the Surface of the Border is covered with Tanners Bark, it will prevent the Frost from penetrating of the Ground to the Roots of the Beans, and be of great Service to protect them from the Injury which they might otherwise receive." Similar advice is given for early peas. Summer mulching, in the strict sense of the word, is not mentioned by Miller, although in several places in the *Gardeners Dictionary* and in the *Gardeners Kalendar* (Miller, 1757) he advises drawing the earth up round the stems of the plants during summer, "which will keep the roots moist, and prevent the sun and wind from drying their stems, to which if they are exposed, it will greatly retard the growth of the plants". Thus, in effect, earthing up is made to answer the purposes of mulching, and may be considered a first step towards it. Loudon, in his *Encyclopaedia of Gardening* (1835), also restricts his use of mulching to frost protection, advising growers to earth up their peas and beans in December, or to cover their stems with ashes, sawdust or old tan ; he also recommends a covering of straw, dry haulm or other light litter during hard frosts.

By the end of the 19th century summer mulching seems to have become common garden practice. J. Wright and H. J. Wright, in their *Vegetable Growers' Guide* (undated), advocate a liberal mulching of manure for runner beans at the end of June, and say that peas always benefit from a mulch of good litter in summer, especially on

light soils. They also maintain that heavy watering and the occasional use of liquid manure, together with a mulching of short refuse manure, will often keep away mildew and thrips. The popular trade papers at the beginning of this century recommend growers to mulch late peas during periods of drought, and William Watson (1925) advises a mulch of litter or leaves for early peas during frost, and of dung or leaf mould for mid-season or late peas during dry weather ; for bush runner beans he says that "a mulching of strawy litter keeps the pods from being badly splashed and also prevents the soil from drying ".

These few scattered references go to show that, in England at least, mulching of peas and beans has long been an accepted practice among gardeners. It is perhaps for this very reason that it has been impossible to find any experimental work on the subject in this country (apart from one trial on paper mulching (quoted Standen, 1930)). A practice that has worked for many years is unlikely to be questioned.

In Sweden, too, mulching peas is an ancient practice, but there seems to have been a good deal of controversy over its value and this has led to scientific trials (Torstensson, 1927-28, 1931). We have not access to the writings of the old Swedish authors, but will quote from the fascinating survey by Torstensson (1931). Here he states that in the 18th and 19th centuries mulching with brushwood or straw was in common use with peas. He quotes Boije (1756) as saying, " Sow your peas and cover them with brushwood, after the manner of the Södermanland farmers, and I assure you that from a quarter of an acre you will get more than another man will from a whole acre." Boije gives no explanation of this favourable effect but Lundström (1842) writes more explicitly : " He who has access to brushwood should always use it to cover his peas. The brushwood protects the tender plants in spring from cold winds and keeps moisture in the soil. It prevents weeds from getting the upper hand among the peas and from spreading over the field. It bears up the pea haulms so that they are not beaten down onto the soil by rain to rot, as often happens where brushwood is not used. Finally it allows the vines to get more air so that they flower more evenly and set more pods, and the pods are nourished and ripen more evenly. He who is not able to get enough brushwood may make do by spreading old waste straw over his pea field." He notes that fresh spruce and pine twigs are the most suitable material for brushwooding and says that these should be laid on the soil in a single layer. This practice " according to experience should give from 20 to 30 per cent increase in yield".

In a later paper (1853), however, Lundström is less enthusiastic, and other 19th-century writers warn growers against the practice. Gerss (1806) reports that opinions concerning the value of brushwooding are highly controversial. He considers that the practice should be " banned from the field for all time ", because its effect

is very uncertain, the labour involved is always considerable, harvesting is made more difficult, the haulms become less valuable, and serious damage is often done to the woods from which the brush is cut. Lundqvist (1840) is also of the opinion that " there can be no question of brushwooding peas on a large scale as the damage caused is greater than the gain ".

As brushwood mulch came into disrepute, straw began to take its place. Hoving (1850) takes a stand against brushwooding and in favour of strawing. He writes, " In order to protect the peas from spring drought one should cover the field immediately after sowing with old straw. It should not be laid in too thick a layer so that the plants can grow through it." Arrhenius (1850), in his famous *Handbook of Swedish Agriculture*, also recommends mulching peas with old straw that is unfit for fodder or other purposes. He claims that this practice has the advantage of preventing the soil from drying out, of suppressing weeds, and of reducing the damage done when the peas are beaten down by rain. He adds that " the straw, by its great ability to absorb moisture from the air, keeps the soil fresher during drought, and from the gradual rotting of the straw one eventually obtains manure ".

Torstensson mentions that many other observations could be quoted, but concludes with the summing up made by Juhlin-Dannfelt (1916) : " In order to suppress weeds it has been the practice at times to cover the field after sowing [peas] with a thin layer of straw. This practice has the advantage of preventing the soil from drying out and of protecting the peas from the wet soil when they lodge ; without straw the stems of the lodged peas would rot and the seeds would drop out of the pods. The damp straw, however, can also prevent the peas from drying at harvest time. . . . The spreading of brushwood on the fields, as was done in earlier times, makes harvesting more difficult, so it is no longer used with field peas grown on a large scale."

Torstensson himself (1931) made a careful study of the effect of strawing on peas in experiments carried out over a period of three years at various places in Sweden. He notes that these trials confirm the experiences of growers that strawing may be beneficial in one case and not in another, and concludes from his own results that the practice can only be relied on to give yield increases in dry years or on dry soils. Early American experiments (Emerson, 1903 ; Montana, 1915 ; Werner, 1933) on the strawing of peas also gave variable results and do not appear to have been continued.

Recently new light has been thrown on the value of straw for legume culture by the fundamental studies carried out at the Legume Laboratory of the Agricultural College of Sweden. This work has shown that strawing encourages the development of legume bacteria, and that its effect is due mainly to the straw's content of certain growth factors (vitamin B_1 and biotin) which were found to be necessary for the growth of the bacteria.

Preliminary field and pot experiments on the effect of strawing not only on the bacteria but on the legumes themselves are reported by Bjälfve (1948). He shows that applications of strawy manure, chopped straw and straw extract all increase the yield of peas, but that the effect is greatest if the soil has been inoculated. This suggests that the increased yields are due, at least in part, to the greater activity of the nodule bacteria. This greater activity may in turn be partly due to the reduced level of soil nitrogen associated with decomposing organic matter, which has been shown to favour fixation of nitrogen (Pinck *et al.*, 1946). This aspect of the effect of mulching on legumes is clearly one that deserves further attention. The only other work that appears to have been done on the subject is concerned with paper mulching (von Bronsart, 1931). These experiments at Hohenheim showed that the roots of pea plants grown on paper-covered soil had 14 per cent more nodules than those on uncovered soil, but there was little difference in the dry weight of the individual nodules. The author concludes that *Bacteria radicicola* is apparently not markedly stimulated by paper mulching.

Apart from straw a number of other loose fibrous materials have been used from time to time as mulches for peas and beans, namely, hay (Geisenheim, 1954 ; New Jersey, 1897), peat (Nikolaisen, 1925-26 ; Reinhold and Schmidt, 1933), woodwool (New Jersey, 1897 ; Reinhold and Schmidt, 1933 ; Reinhold, 1942), glass wool (Verma and Kohnke, 1951 ; Weger, 1951a), padi husk (Smith, 1955), bagasse (Gilbert, 1956) and sawdust (Agassiz, B.C., 1954 ; Fletcher *et al.*, 1952 ; Lyndon, 1947 ; Matthews, 1948 ; Smith, 1955 ; Woods, 1951). Of these, sawdust appears to be the most promising for dry regions. One problem that has confronted British Columbian growers is that certain types of sawdust appear to have a toxic or stunting effect on the crops. This problem has been investigated recently (Newton, 1953), with the result that cedar (*Thuja plicata*) sawdust was proved to have a pronounced toxic effect on peas and beans, resulting in reduced germination and suppression of seedling growth. The other types of sawdust extensively used in British Columbia, i.e. fir (*Pseudotsuga taxifolia*), hemlock (*Tsuga heterophylla*) and balsam (*Abies grandis*), had little or no depressing effect when the seed was sown in the pure sawdust. Balsam, in fact, slightly improved the growth of beans. When they were incorporated with the soil, however, without additional nitrogen, a stunting effect was observed. In this case the depression of growth was a measure of the rate at which the sawdust was decomposed by soil organisms, and was not a direct toxic effect such as was shown by cedar. It appears therefore that fir, hemlock and balsam sawdusts are not likely to have any undesirable effects when used as a mulch on the surface of the soil, especially if sufficient nitrogen is applied, but that cedar sawdust should be avoided.

The value of black or white coloured mulches has been tested at

various times on legumes both from the point of view of regulating soil temperatures and of increasing light reflection. The materials used have included small coal and granulated marble (Wollny, 1897-98), black and white mulch paper (many authors), black plastic (Emmert, 1956a and b), grey and whitewashed slates (Weger, 1951b) and aluminium foil (Tiedjens, 1950 ; Wall, 1950).

Effects of Mulching

On yield

Peas require relatively cool, moist soil conditions with good drainage. One would therefore expect temperature-reducing mulches, such as straw or sawdust, to be of most value in hot climates or under dry conditions, whereas soil-warming mulches, such as black paper, should be most useful for early sowings before the soil has warmed up. Early experiments with straw mulching of peas in the United States were not encouraging, but too few data are given to allow conclusions to be drawn. In the northern state of Montana normal cultivation gave better results than strawing (Montana, 1915), and in the warm central state of Nebraska results over a period of three years were variable (Emerson, 1903). Later Swedish work is more informative. Torstensson (1931) reports on trials carried out at a large number of places during three years. In 1928, a year with plentiful rainfall during early summer, mulching with chopped straw had either a detrimental or insignificant effect on yield with one exception (viz. on a spring-ploughed (i.e. drier) field where yields were increased by 25·6 per cent). This suggests that the mulched crops generally suffered from excessive moisture and waterlogging, or at least that the mulch was unnecessary for moisture conservation. In the following year, in which rainfall was again good, only two out of six trials showed a significant increase in favour of strawing, the maximum increase being only 14·2 per cent. In 1930, however, when there was a very warm, dry spring, strawing had a strikingly good effect. Five out of seven experiments gave a significant increase for strawing, in one case as much as 42·1 per cent ; in the remaining two trials mulching had no effect. From these very extensive experiments Torstensson concludes that strawing can only be relied upon to increase yields in a dry year or on dry soils. It is quite probable that in areas further south the cooling effect of straw might be beneficial even where moisture was not a limiting factor, but this has yet to be demonstrated. In a more recent Swedish experiment (Bjälfve, 1948) both chopped straw and strawy manure mulches improved yields of peas, the increases being 10 and 32 per cent respectively on non-inoculated soil and 17 and 39 per cent on inoculated. Weather conditions in this case are unfortunately not reported, but the good effects are attributed to the straw's content of certain growth factors which are necessary for the growth of nodule bacteria. If this theory is considered in

conjunction with Torstensson's results it would seem that in a wet year the excessive moisture under straw would counterbalance the beneficial effect of the growth factors, possibly by making conditions unsuitable for bacterial development.

That sawdust mulching is also most effective under dry conditions is shown by recent work in British Columbia. At Saanichton the summer rainfall is very low, the total precipitation from April to September averaging only 6·57 inches (39 years' average). Here mulching peas with a 2-inch layer of sawdust gave a " distinct trend towards increased yields " (Woods, 1951). At Agassiz, however, the average rainfall for the same summer period is 20·34 inches (61 years' average), and here sawdust mulching had no effect on the yield of peas (Agassiz, B.C., 1954). Consistently favourable results, therefore, can only be expected in districts where dry summers are the normal rule.

Paper mulching has been tested on peas in various parts of the world with very varying results. The first trials in America (Flint, 1928) gave a spectacular yield increase (181·5 per cent) in the first year but only a small increase (11·5 per cent) the following year. In a trial in England (quoted Standen, 1930) paper mulching more than doubled the yield of April-sown peas. Other authors from the United States, Germany and Canada report smaller and very variable increases (Hutchins, 1933 ; Magruder, 1930 ; Reinhold and Schmidt, 1930a ; Sidney, B.C., 1928), while in yet other trials in Germany, France and Czechoslovakia there was no effect on yield (Anon., 1926 ; Boresch, 1932 ; de Marcillac, 1930). A carefully planned, long-term trial would be needed to determine the conditions under which paper mulching increases yields, but as the practice has so many technical and economic disadvantages the results would only be of academic interest.

Beans. Broad beans (*Vicia faba*), unlike most other types of bean, require cool conditions. It is therefore surprising that the only work reported on the mulching of this crop was carried out with paper mulch (quoted Standen, 1930). The trial was made in England and it is stated that " with mulch paper the first crop of broad beans was double that of the unmulched ". The good results are probably due to the fact that temperatures are normally low during the growth season of the first broad bean crop in this country. Black plastic mulch has been tested recently [see Fig. 9], but the results do not appear to have been published.

Kidney beans (*Phaseolus vulgaris*) are warm season plants. They are the most important species grown in the United States, so where American authors refer to bean with no further qualification we have assumed that kidney bean is meant. A strawing experiment with this crop was carried out in the hot state of Nebraska over a period of four years (Werner, 1933). Without irrigation yield increases averaged 74 per cent, whereas with irrigation the average increase was only 27 per cent. There were

serious drought periods in three out of the four seasons. The benefit, therefore, seems to be largely due to moisture conservation. In Yugoslavia, too, mulching with a 10 cm. layer of straw improved soil moisture conditions and gave considerable yield increases over a three-year period except where irrigation was used (Rosić, 1955). Hay and woodwool were tested in an early experiment in New Jersey (New Jersey, 1897) in a hot wet season. Only the April-sown crop gave a yield response slightly in favour of mulching, the August-sown crop being unaffected ; probably moisture was adequate in the autumn, even in the uncovered soil. Similarly an irrigated crop at Geisenheim showed no benefit from hay mulching (Geisenheim, 1954). Grass clippings reduced yields in one season in Ohio but no details of the trial are given (Ohio, 1922). In Uganda, however, responses to grass mulch were consistently positive in trials at three places, the average yield increase being 24 per cent ; additional nitrogen treatment (2 cwt./acre sulphate of ammonia at planting) increased the mulch effect at one place but reduced it at the other two (Uganda Protectorate, 1955). In Hawaii mulching with sugar-cane bagasse has been used very successfully to reduce manganese toxicity on highly manganiferous soil (Gilbert, 1956). On such a soil bagasse mulch treated with solutions of iron and ammonium phosphate doubled the yield of green beans, and even untreated bagasse mulch increased yields by 2,689 lb. per acre over the controls. It is considered that the benefit was due to lower soil temperatures and prevention of drying out which reduced manganese intake. It was also found that furrow irrigation could be used under a bagasse mulch provided that wide bottomed furrows with gently sloping sides were used, and that dry Sudan grass was placed lengthwise in the furrows to retard movement of the bagasse.

Peat, woodwool and coke dust were used on sandy soil in Germany (Reinhold and Schmidt, 1933), and it was found that all three mulches reduced the soil temperature but only peat was effective in increasing the soil water content. Peat, moreover, was the only material that gave a significant yield increase (14·1 per cent) with dwarf beans. On a heavy soil peat gave a similar increase of 18·8 per cent (Nikolaisen, 1925-26). A layer of coal gave a slight increase in bean yields in Yugoslavia but was much less effective than straw (Rosić, 1955). In a German trial (Weger, 1951a) beans mulched with glass wool yielded only 93 per cent of the controls ; the unfavourable effect is attributed to the sponge action of the glass wool which absorbed light showers. Sawdust mulching tended to increase bean yields at Saanichton, B.C., where droughts are serious during the summer (Woods, 1951). Thus, of the voluminous mulches, straw, peat and sawdust have been used successfully under dry conditions.

Paper mulching trials with kidney beans have been numerous. Some authors report phenomenal yield increases, such as 420 per

cent in Germany (Otto, 1926), 318 per cent in Quebec (La Ferme, Quebec, 1931), 113, 153 and 225 per cent in three out of five trials in Virginia (Flint, 1928), and 137-200 per cent (depending on variety) in Germany in a very wet season when the paper kept the soil in better condition than the controls (Schomerus, 1927). Although these are exceptional cases, the majority of authors report some increase in yield as a result of paper mulching (Agassiz, B.C., 1931 ; Böhnert, 1926 ; Canada, Div. Hort., 1930b, 1931 ; Edmond, 1929 ; Fredericton, N.B., 1930 ; Lerch, 1930 ; Magruder, 1930, 1931b ; Morden, Man., 1930 ; Nikolaisen, 1925-26 ; Sidney, B.C., 1929 ; Thompson and Platenius, 1932 ; Werner, 1933 ; Woods, 1937 ; v. Wrangell, 1928). A decrease in yield or no significant effect was obtained in nine trials (Agassiz, B.C., 1930 ; Boischot, 1930 ; Boresch, 1932 ; Florida, 1930 ; Kapuskasing, Ont., 1930 ; Langer, 1927 ; Reinhold and Schmidt, 1930a ; Shaw, 1926 ; Summerland, B.C., 1930), while in a few cases the response varied from positive to negative depending on variety and season (Hutchins, 1933 ; Magruder, 1928). It is not possible from the information available to generalize on the effects of paper mulching on kidney bean yields. One can only say that under the right conditions this heat-loving crop is capable of responding very favourably. Unfortunately the right conditions have not been exactly determined and appear to depend on a complex of interrelated factors.

It is interesting that in the one comparison that has been made between black and white paper (Magruder, 1930) the black gave the better results with both early and late green pod beans and late wax pod ; early wax pod yielded slightly better with the white mulch. This trial was made in Ohio where a drought occurred in late summer. Recent trials in Germany (Weger, 1951a and b), however, suggest that a white cover may have a more beneficial effect on yields than a dark one. When French beans were mulched with grey or whitewashed slates during a very dry season there was a yield increase of 45 per cent for the white slates and only 33 per cent for the grey ones. The value of the white cover, in spite of the lower temperatures it produced, was attributed to the stronger radiation and shorter wave length of the light reflected from it. Confirmation of this theory is given by the good results that have been obtained with aluminium foil mulch (Wall, 1950), which also reflects a high proportion of the light falling on it and reduces soil temperature during hot weather. Snap beans mulched with this material during a three-year period in Virginia gave a yield increase of 50-100 per cent over the controls.

Covering the soil with black plastic, a material which appears to be very effective in warming the soil, conserving moisture and suppressing weeds, has given excellent results in a recent trial in Kentucky (Emmert, 1956a and b). Snap and pole beans sown through the plastic with a corn jobber were harvested two weeks earlier and produced 200 bushels per acre more than the controls.

It was found possible to use furrow irrigation under the mulch by cutting T-shaped slits in the plastic above the furrows.

The lima bean (*Phaseolus lunatus*) requires a relatively long warm period for maturation. Straw mulching in combination with irrigation reduced yields of this crop by an average of 33 per cent in Nebraska (Werner, 1933), possibly owing to retarded maturity. Strawing alone, however, was beneficial, giving a 28 per cent yield increase. Further north, in Delaware, strawing had no significant effect on yield in a two-year trial (Rahn, 1955). In a very dry season in Ohio mulching with grass clippings gave a 29 per cent yield increase (Ohio, 1922). In the Nebraska trial mentioned above paper mulching together with irrigation had little effect, whereas paper alone gave an average increase of only 11·5 per cent (rather surprisingly, lower than that from strawing). In one drought year in Ohio paper mulching increased the crop by as much as 166 per cent (Magruder, 1931b), but in other American trials the results have only been moderate (Flint, 1928 ; Hutchins, 1933 ; Magruder, 1928, 1930). White paper had little effect on yield (Magruder, 1930).

The soya bean (*Glycine max*) is very resistant to drought but nevertheless appears to respond well to moisture-conserving mulches. In trials in Indiana in 1948 and 1949 mulches of wheat straw, maize stover and glass wool all increased yields, the average increase for the three mulches being 6 and 3 bushels per acre in the two years ; there were only slight differences between the effects of the three materials (Verma and Kohnke, 1951). In trials in Illinois on a silt loam strawing made little difference in a year with good rainfall but increased yields by 28 per cent in a drier year (van Doren and Stauffer, 1944). A 6-inch mulch of sawdust or padi husks applied to tapioca had no residual effect on the following crop of soya beans in Malaya ; the bean yields were better when extra nitrogen was applied to the mulch residue but not significantly so (Smith, 1955). Response to paper mulching has been tested in trials carried out for two years in Czechoslovakia (Boresch, 1932). The soil was a sandy loam and therefore one in which paper mulching would not greatly affect moisture content. In the first year a late maturing variety was used and a very good yield increase of 103 per cent was obtained with black paper ; with white paper the increase was not significant. The following year, using a variety of unknown origin, the increase was only 24 per cent with black paper. The author considers that the difference in response was probably due to a difference in maturation period, the second variety being earlier. He points out that, as in the case of tomato and sweet corn, the success of paper mulching has been reduced by the use of early varieties which have lower heat requirements than the later ones. The effect of variety on response is also apparent in the results obtained by v. Wrangell (1929b), in which a Dutch variety gave a 68·7 per cent increase as a result of paper mulching and a Japanese variety gave only 11·1 per cent.

On growth and maturity

Few observations have been recorded on the effect of mulching materials on germination of legumes. Peas, unlike the small-seeded crops, emerged fairly well when sown directly into a 2-inch mulch of sawdust (Woods, 1951), and also when sown in the soil under a 3-inch mulch (Matthews, 1948), or on the soil surface under a 3- or 4-inch layer (Lyndon, 1947). Cedar (*Thuja plicata*) sawdust, however, was found to have a phytotoxic effect and greatly depressed germination of both peas and beans (Newton, 1953). Aluminium foil hastened germination of beans by two days and produced a more even stand of plants (Wall, 1950). Paper mulching has sometimes been observed to hasten germination of beans slightly (Canada, Div. Hort., 1930b, 1931 ; Morden, Man., 1930 ; Werner, 1933), although Hutchins (1933) found that it retarded emergence of beans and did not affect that of peas. Musso (1932) reports that it was a common experience in Russia for paper-mulched seed to germinate more rapidly than the unmulched, but for the young seedlings to die a few days after emergence. This phenomenon, which was confirmed by his own experiments even with heat-loving crops such as beans, he attributes to the high temperatures in the upper soil layer under black paper, which were injurious to the young roots. Since workers elsewhere have not had the same experience, this would probably only be the case under conditions of great heat. Snap and pole beans sown through a black plastic mulch emerged a week ahead of the controls and gave a better stand as the unmulched soil crusted badly (Emmert, 1956b).

With regard to vegetative growth, the effect of strawing is not clear. Torstensson (1927-28, 1931), in trials at many different places in Sweden over a period of four years, found that in almost every case strawing increased the amount of haulm. He points out that this gives confirmation to the theory that vegetative growth is favoured by conditions in which the soil temperature is lower than the air temperature. There seemed to be no relationship between vegetative growth and yield. Werner (1933), on the other hand, carried out trials with a wide range of vegetables, including beans but not peas, and found that strawing reduced the early growth of all the vegetables, and that the top growth remained smaller throughout the season. In spite of this bean yields were generally increased by strawing. In the same series of trials paper mulching, which tended to increase soil temperature, stimulated the early growth of all vegetables. At the end of the season, however, the plants were usually smaller than on the unmulched plots but more productive, as was the case with strawing. Several other authors report greater vegetative growth of legumes under paper mulch, either during the early stages or throughout the season (Anon., 1926 ; Boischot, 1930 ; von Bronsart, 1931 ; Canada, Div. Hort., 1930b, 1931 ; Flint, 1928 ; La Ferme, Quebec, 1931 ; Morden, Man., 1930 ; Mutzek, 1926 ; Reinhold and Schmidt, 1930a and b ; Werth, 1930). On the other

hand Bassi (1930) mentions that paper mulching had no effect on vegetative growth of beans, Shaw (1926) records lower plant weights from the mulched plots, and Langer (1927) says that paper mulched beans gradually became brown and died whereas the control plants remained green and bore a fair crop. In another German trial runner beans were so damaged by the heat radiated from the paper during a hot spring that the trial was a failure, although dwarf beans and peas were not injured (Anon., 1926). In the great majority of these cases more vigorous vegetative growth was associated with increased yields and vice versa. Black plastic mulches stimulated early growth of snap and pole beans (Emmert, 1956b). Comparing the growth of dwarf beans mulched with black and white slates, Weger (1951b) found that elongation was initially most rapid with the white slates but that there was no difference at the end of the season when plants on both covered plots were 17 per cent larger, and also more productive, than the controls. Leaf growth was more luxuriant with the black than the white slates. Snap beans mulched with aluminium foil " showed more development from the beginning, appearing to be, at the time of flowering, from one-half to twice as large, with more blossoms. Mulched plants showed better growing color and stayed green longer." (Wall, 1950). In this case, too, stronger growth was associated with higher yields.

Emerson (1903) reports that straw mulching retarded the maturity of beans and recommends that late varieties or late sowings should not be mulched, owing to the danger of frost. Sawdust also delayed maturity of peas and beans by reducing soil temperatures (Woods, 1951), and lengthened the harvest period for peas by five days (Agassiz, B.C., 1954). In home gardens this might be of great advantage. Maturity was hastened or early yield increased by black paper in a large number of cases (Agassiz, B.C., 1931 ; Boresch, 1932 ; Edmond, 1929 ; Florida, 1930 ; Lerch, 1930 ; Thompson and Platenius, 1932 ; Werner, 1933 ; Woods, 1937). Magruder (1930) found that both black and white paper hastened ripening of early and late green pod beans and early wax pods, whereas they delayed maturity of late wax pods; with peas, black paper increased and white paper decreased early yield. In German trials paper had no effect on the earliness of peas but enabled dwarf beans to be harvested before the frost which killed the unmulched plants (Anon., 1926). In a few cases paper mulching is reported to have had no effect on earliness (Bassi, 1930 ; Boischot, 1930 ; La Ferme, Quebec, 1931 ; Reinhold and Schmidt, 1930a and b ; Sidney, B.C., 1928). A cover of white slates gave earlier yields of dwarf beans than did black slates, owing to the stronger radiation and shorter wavelength of light reflected from them (Weger, 1951b). Both bunch and Kentucky Wonder beans mulched with black plastic were harvested two weeks earlier than the controls and could thus be sold at a much higher price (Emmert, 1956a and b).

On quality

The effect of mulching on the quality of the crop is an aspect of the subject that has received very little attention. In fact it has only been mentioned by three authors. Standen (1930) quotes a report on English trials with paper mulching, which says " A row of garden peas sown under mulch . . . averaged 36 pods per plant, with not less than 8 peas in a pod, all very regular and fine. Peas without the mulch yielded less than half the number of pods, and these were very irregular in size and quality." Magruder (1930) also mentions that peas grown under black and white paper had longer pods which were better filled and freer from dirt, while the quality of bush lima beans was improved, and green pod and wax pod beans were cleaner. Emmert (1956a) says that a plastic mulch eliminated ground spattering of beans.

On pests and diseases

Nowadays most growers would be sufficiently hygiene-conscious not to consider using the dead and possibly diseased residue from one crop as a mulch for a related crop, even though this might appear a simple and cheap method of obtaining mulch material. Experimental evidence of the spread of disease from such material was obtained by Halsted (New Jersey, 1896), who used old bean pods infected with anthracnose (*Colletotrichum lagenarium*) as a mulch for the following crop of wax beans. Although the yield of good pods on the mulched plots was about the same as that on the controls, the yield of spotted pods was more than three times as great. It is clearly a dangerous practice. Halsted later found that mulches of fresh hay, salt hay or excelsior had no effect on the prevalence of anthracnose or bacterial leaf blight (New Jersey, 1897).

There is an old belief in England that mulching peas with manure will help to keep them healthy. Wright and Wright (undated), at the end of the 19th century, stated that " many an attack of thrips or mildew on peas has been nipped in the bud by a liberal drenching of liquid manure, followed by mulching with short manure, as it certainly could not have been by any insecticide or fungicide ". Although there is no experimental evidence available on the point, the theory is probably well founded, as both troubles are most serious in warm, dry weather. By keeping the soil cool and moist and preventing a check to growth mulching might well increase resistance to attack.

In the series of investigations carried out at the Florida Agricultural Experiment Station to determine the value of mulching crops grown on root-knot infested soil (Florida, 1938-1951), peas were among the crops tested with favourable results (Florida, 1944 ; Watson, 1944). The plants made better growth on the mulched plots than on the controls, the deeper the mulch the better being the results. The type of mulch material (leaves, grass, weeds, etc.)

did not seem to affect the results, provided it decayed quickly and covered the ground well. In a later experiment (Florida, 1950), however, a heavy mulch of forest leaves gave much better results with peas than a similar mulch of miscellaneous plant material such as weeds and grasses. The average yields obtained were 1,090 lb. per acre for leaves, 477 lb. for miscellaneous plant material, and 852 lb. for the controls. In any case mulching appears to be only a palliative measure, for the experiments as a whole showed that although heavy mulches generally improved the growth and yield of plants on root-knot infested soil they did not actually control the nematode. A factor which may be responsible for this better growth under mulch, but which does not appear to have been considered in this connection, is the well known potassium-increasing effect of mulches. This factor seems worth investigating in view of the fact that Oteifa (1952) found that inoculation of lima bean plants with *Meloidogyne incognita* reduced the K content, and that greatly improved growth of nematode-infested plants could be obtained by increasing the level of K supply.

It has been claimed that sawdust mulch prevents birds from pulling out the young peas (Lyndon, 1947 ; Matthews, 1948), and keeps slugs away from the plants (Matthews, 1948).

In tests in Virginia, the use of aluminium foil mulch prevented damage to beans by Mexican bean beetle (Tiedjens, 1950). The author suggests that this may be due, at least in part, to the glare from the shiny foil which might discourage adult insects from alighting on the leaves. Wall (1950) also reports foil mulching trials from Virginia which appear to be the same ones. He notes that " while the plants were still small, there was a considerable difference in the amount of Bean Leaf Beetle damage for the two treatments. Plants mulched with foil showed no harmful damage ; foliage on the cultivated plants was full of holes ". As the pests are not referred to by their scientific names it is not clear whether Mexican bean beetle (*Epilachna varivestis*) and bean leaf beetle (*Cerotoma trifurcata*) were both concerned, or whether the authors are in fact both referring to the same pest.

Economics

Almost all the opinions expressed on the economics of legume mulching are concerned with paper mulching. Reinhold and Schmidt (1930a and b) give a detailed analysis of the costs and returns for many vegetables, including peas on moor soil and beans on mineral soil, grown under paper mulch. The high cost of paper, even of the relatively cheap Natronag paper, greatly outweighed the saving in cost of cultivation. With beans the yield of the mulched plants was unaffected or lower than that of the controls, so the practice was highly uneconomic. With peas mulching resulted in a 9·5 per cent increase in yield, but this was not nearly enough to cover the increased costs of production. Many other

authors endorse this opinion that paper mulching is uneconomic for peas and beans, even where yields and earliness are favourably affected, citing the prohibitive cost of the paper, its unsuitability for use a second year, the labour required in laying it or the relatively low value of these standard crops (Boresch, 1932 ; Canada, Div. Hort., 1931 ; Flint, 1929 ; Lerch, 1930 ; Sidney, B.C., 1929 ; Straight, 1938 ; Werth, 1930 ; Woods, 1937).

With regard to other materials, peat, Wega mulch and coke dust all had so little effect on the yield of beans on a dry soil that their use is not considered justified (Reinhold and Schmidt, 1933). Slates, on the other hand, were very beneficial and have been recommended for use in areas where they can be obtained cheaply as waste building material (Weger, 1951b).

Conclusions

No material has taken the place of the traditional short manure mulch, formerly used in England on peas during summer drought.

Strawing is most likely to be of benefit during dry years or on dry soils. It may retard maturity and prove detrimental in wet seasons. Further studies on the effect of straw on nodule bacteria might produce interesting results.

Sawdust will also increase yields of peas and beans under dry conditions. It tends to retard maturity but to lengthen the harvest period. *Thuja plicata* sawdust has a phytotoxic effect and should be avoided.

Paper mulching has given variable results, generally better with beans than with peas, but the high cost is not economically justified.

Slates, especially when whitewashed, are worthy of further trial.

Aluminium foil has given good results and prevents damage by Mexican bean beetle, but it may be too expensive for commercial use.

Black polyethylene plastic shows promise for hastening cropping.

By courtesy Dominion Experimental Farm, Saanichton, B.C.

FIG. 1. GATHERING SAWDUST.

Box pushes readily into sawdust, but not as readily into shavings.

[*By courtesy Dominion Experimental Farm, Saanichton, B.C.*

FIG. 2. DISTRIBUTING SAWDUST.

Sawdust being dumped and spread. It took six hours of tractor labour and seven hours of hand labour to spread 6,200 cubic feet (31 units) of sawdust over $\frac{3}{4}$ acre.

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[*By courtesy Dominion Experimental Farm, Saanichton, B.C.*

FIG. 3. WEED CONTROL BY SAWDUST MULCH.

A view showing the effective control of weeds by a 2-inch sawdust mulch. The plot in the foreground was kept cultivated during the summer of 1950 and volunteer grass germinated in the autumn and grew during the winter of 1950-51.

[*By courtesy Dominion Experimental Farm, Saanichton, B.C.*

FIG. 4. INCORPORATION OF SAWDUST MULCH.

Incorporating a 4-inch application of sawdust into the soil to a depth of 11 inches with a rotovator. Two trips over resulted in a uniform incorporation. A heavy dressing of ammonium nitrate was applied to offset nitrate depression.

[*By courtesy Dominion Experimental Farm, Saanichton, B.C.*

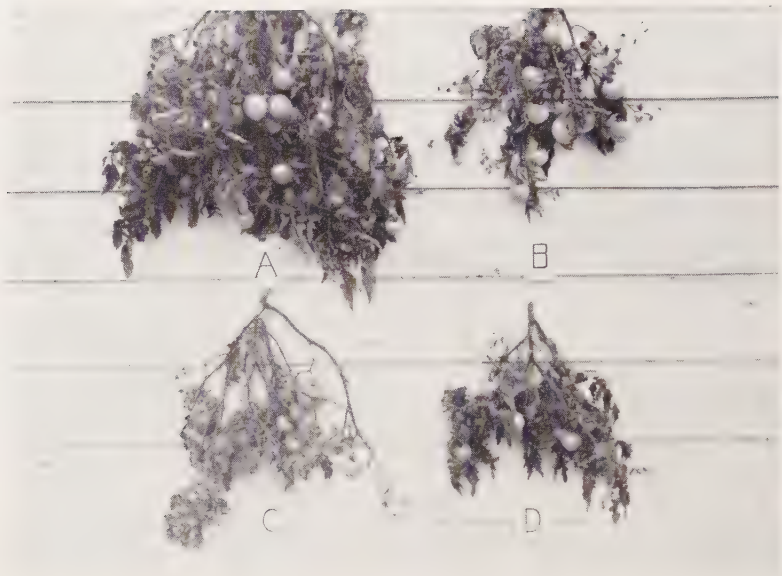
FIG. 5. MULCHING CARROTS.

Nantes carrots grown in clay soil provided with (A) 2-inch sawdust mulch, (B) 1 inch sawdust incorporated, (C) 4 inches sawdust incorporated, (D) 20 cubic yards manure per acre (check). The grade was higher but yield lower from the C plots than from the A plots.

[*By courtesy Dominion Experimental Farm, Saanichton, B.C.*

FIG. 6. MULCHING RADISHES.

French Breakfast radish grown under 2-inch sawdust mulch (1) and under no mulch (2). Roots were distinctly longer and smoother when grown under sawdust.



[*By courtesy Dominion Experimental Farm, Saanichton, B.C.*

FIG. 7. MULCHING TOMATOES.

Tomato plants from (A) continuous 2-inch sawdust mulch, (B) 1 inch sawdust incorporated, (C) 4 inches sawdust incorporated, (D) Check (20 cubic yards manure per acre).

[*By courtesy Dominion Experimental Farm, Saanichton, B.C.*

FIG. 8. MULCHING MELONS.

Effect of paper mulch on cantaloupes.

FIG. 9. BROAD BEANS MULCHED WITH POLYTHENE.

By courtesy Geo. Monro, Ltd.

Visqueen black polythene film 200 gauge (0·002 inch) perforated mechanically.

CHAPTER 9

POTATOES

General

In some of the potato growing districts of the world, such as the central and southern United States, high summer temperatures appear to be the limiting factor in the production of high yields. Jones *et al.* (1922) carried out experiments with potatoes grown at different soil temperatures and found that the greatest growth of tubers occurred at 64·4° F. while the tops grew most rapidly at 69·8° F. Growth of tubers declined very rapidly at higher temperatures. Bushnell (1925) confirms that the optimum temperature for yield is near 64° F. and found, moreover, that at 84·2° F. no tubers were formed. Both these experiments show that growth of the tubers is more retarded by high temperatures than growth of the tops. Bushnell considers the explanation of this to lie in the fact that an increase in temperature above the optimum causes an increase in respiration without a corresponding increase in photosynthesis, which results in a decrease in the amount of carbohydrates available for tuber growth. It seems obvious, therefore, that in districts where summer temperatures normally exceed the optimum any treatment that will reduce the soil temperature is likely to prove beneficial. If such treatment is applied in the early part of the season, however, while the soil is still cool and tuber formation has not started, it is likely to retard the early growth of the plants and so have a detrimental effect on yield and time of ripening.

Mulching with organic material such as straw, with its known effect of lowering soil temperature, has been fairly widely tested for this purpose in America. As a commercial practice, however, straw or hay mulching has only become established to a limited extent and in certain areas, notably Ohio and Nebraska (Hardenburg, 1949). Recently its use has been recommended in other hot countries such as Israel (Amir, 1948 ; Crispin, 1943), India (Saptharishi and Azariah, 1954) and Colombia (Ernesto Arango, 1948). In England no work has been done on the straw mulching of potatoes, presumably because temperatures during the growing season generally approach to the optimum (Burton, 1948).

Low rainfall appears to be a less important factor than high temperatures in limiting the growth of potatoes. In a review of the literature Bushnell (1926) shows that the total water requirement of the crop is only about 10 inches, provided the water is received at frequent intervals, but if drought periods occur the total water requirement is much higher. Moreover, the water requirements

of the plant are highest during the later stages of its vegetative cycle which, in districts like the central states of America, are likely to coincide with weather conditions in which evaporation exceeds rainfall. As one might expect, mulching as a moisture conserving practice has proved of benefit on unirrigated land in areas where periods of summer drought are common (Pieper *et al.*, 1930 ; Werner, 1929b ; Werner *et al.*, 1951 ; and others), and also on irrigated land as a means of reducing the amount and frequency of irrigation required (Amir, 1948 ; Crispin, 1943). In areas with low evaporation and a regular summer rainfall, however, even if this is small, potatoes are not likely to benefit from the moisture conserving action of a mulch.

Another purpose for which mulching has been used experimentally on potatoes in some parts of the world is to increase soil temperatures and thus to hasten early growth and maturity. For this purpose black asphalt paper, which absorbs the sun's rays, has been used. In spite of the fact that in many cases paper has increased yields and earliness of potatoes, investigators have almost unanimously come to the conclusion that with this low-value standard crop the increased returns obtained do not justify the extra cost involved (Hutchins, 1933 ; Smith, 1931 ; Straight, 1938 ; and others).

Both straw and paper mulches increase the danger of frost damage (Petit, 1931 ; Werner, 1933), so should not be used in districts where spring frosts are likely to occur after the potatoes are up.

In addition to straw and paper, a wide variety of other materials has been used for mulching potatoes. A report from Illinois mentions that corn stover, strawy manure, low grade grass and legume hays have all been used on a small scale (Pieper *et al.*, 1930), while in a popular article from Massachusetts potatoes are said to have responded well to hay and grass clippings (Anon., 1943), and Hardenburg (1949) includes leaves in the list. In Columbia maize stems, ferns or *Chloris* hay are used (Dodds and Hawkes, 1952 ; Ernesto Arango, 1948). Emerson (1903) included coarse stable manure in his trials. In Maine unchopped green grass, green clover and sawdust were tested (Maine, 1948), and the use of sawdust for potatoes has been tested or commented on by a number of other authors (Apsits, 1931 ; Fletcher *et al.*, 1952 ; Johnson, 1944 ; Oregon, 1952 ; Terman *et al.*, 1948 ; Webster *et al.*, 1953 ; Woods, 1956). Reeds have been used in Russia and India (Karnauhov, 1949 ; Saptharishi and Azariah, 1954) and chaff and manure in Yugoslavia (Drezgić, 1953). Wega mulch, a type of woodwool, was investigated in one trial in Germany (Reinhold, 1942). Recently aluminium foil, with its light reflecting properties, has been receiving attention in America and potatoes have been included among the test crops (Wall, 1950). The properties common to all these materials are reduction and stabilization of soil temperatures (with

the exception of black paper), moisture conservation and weed control. They may differ in their degree of efficiency and in their secondary effects, such as influence on soil nitrates, incidence of pests and diseases and possibility of efficient crop management. In general, however, the overriding factors determining choice of material for commercial use appear to be the economic ones—availability and cheapness.

Effects of Mulching

On yield

Straw and hay. Mulching with these materials is clearly most likely to result in increased yields of potatoes in districts where summer temperatures are high and periods of drought are common. This is confirmed by reports from the United States, in which workers in the southern and central states have generally obtained increased yields from straw (except where soil or seasonal conditions proved unsuitable), whereas workers in the northern states usually report reduced yields.

The most southern state from which experimental results are available is Oklahoma. In a trial at the end of the last century (Waugh, 1895), the application of straw soon after the plants were up considerably increased both total yields and the percentage of marketable tubers. Morris (1901), also working in Oklahoma, obtained good increases in yield of midseason potatoes (about 27 per cent) during the first two years of a trial, while in the third year, which was exceptionally dry, the yield from the mulched plots was about four times that from the cultivated plots. These results were obtained on a sandy soil. As will be seen later, mulching has not given such consistent results elsewhere, especially on less well-drained soils.

In Ohio summer temperatures are above the optimum for the development of the potato crop (Bushnell, 1926). As early as 1882 experiments were started at Columbus (central Ohio) on the value of straw mulches, the soil being a clay loam and the straw being applied at planting time (Ohio, 1883-1885). The first year the results were invalidated, and in the second year yields were considerably reduced as the early part of the season was so wet and cold that the mulched plots were very slow in emerging and made a poor stand. In spite of this unpromising beginning it was still considered that mulching might prove successful in a dry season, and this confidence was justified in the following year when conditions at planting time were favourable and yields were increased by an average of 49·6 bushels per acre. During the early part of this century Ohio growers again tried mulching with straw but beneficial results were not consistently obtained (Bushnell and Welton, 1931). Bushnell and his associates (1930, 1931) throw some light on the reasons for these variable results by investigating more

closely the effects of weather and soil conditions and time of mulching. They found that in northern Ohio in an exceptionally hot, dry season straw mulching reduced soil temperatures at a depth of 1 inch by an average of 5·5° F. during June-September, the difference sometimes amounting to as much as 29° F. ; it also maintained a higher water content in the soil. In this season maincrop potato yields were approximately doubled by straw mulching. In the following year, however, with abnormally heavy rainfall in September and October, mulching was detrimental on a silt loam soil as the straw impeded evaporation and run off. In a third year, rather cooler than normal, results varied largely owing to soil variation but on the average yields were increased. In every case straw was applied within two weeks of planting. On the basis of these results Bushnell considered that the use of straw might be more consistently beneficial on soils which drained more rapidly and in districts with a higher summer temperature. To test this theory experiments were carried out in southern Ohio with the result that yet a third factor was found to be operative, namely time of mulching. In these tests yields of early potatoes were increased in each of two years by mulching after the plants were up. Mulching at planting time, however, retarded early growth, caused symptoms of nitrogen deficiency and had less good or even detrimental effects on yield. These experiments in Ohio indicate that straw mulching may be beneficial in the southern parts of the state and in hot, dry summers in the northern parts, but that it should only be used on well drained soils, and the mulch should not be applied too early in the season for fear of keeping the soil too cool. The danger of mulching potatoes on poorly drained soils has also been specifically pointed out by other authors (Emerson, 1903 ; Pieper *et al.*, 1930) and is, moreover, confirmed by the reduced yields that have often been obtained on heavy or silt soils in years of heavy rainfall. The danger of mulching too early in the season had been previously pointed out by Emerson (1903, 1907).

In eastern Nebraska July temperatures average 75-80° F. and frequently reach much higher levels. This is the period of greatest tuber development in the early potato crop (Werner *et al.*, 1951). At the beginning of the century Emerson (1903) stated that potatoes and strawberries had probably been mulched more than any other crop but that results had varied. Experimenting with early potatoes straw mulched six weeks after planting, he obtained a fair increase in yield in a dry summer, a slight increase in a rather wet summer and a slight decrease in an exceptionally wet summer, the detrimental effect being greater on poorly drained, lowland soil than on an upland soil. He also found that, in a wet season, applying straw at time of planting decreased yields by 11 per cent, whereas delaying mulching until late summer increased yields by 11 per cent. Like Bushnell and Weaver (1930) he recommends that early potatoes should not be mulched until the soil is warm. He concludes that

mulching usually increases yields except in very wet seasons or soils which are rare in Nebraska. Continuing these experiments (Emerson, 1907) he found that mulch when properly applied increased yields by as much as 40 per cent, whereas it would decrease yields when wrongly applied. From the whole of seven years' experience he cautiously concludes that mulching with old hay or straw is a fairly satisfactory method of growing potatoes on a small scale but is only economical if mulching material is cheap. Werner (1929b), also working in Nebraska, obtained increased yields from straw mulching just before emergence in four seasons out of five, the season in which no benefit was obtained being cool and wet. As might be expected, the increase was greater with the early crop, in which the period of tuber development coincided with the hot, dry summer months, than with the late crop when tubers developed during the cooler weather of September. He also found that irrigation was of more value on the cultivated than on the mulched plots, but that a combination of straw mulching and irrigation increased yields more than the use of either practice alone ; this seems to indicate that the benefit obtained from straw was due not only to the conservation of moisture but also to some other factor, presumably reduction of soil temperature. Later (Werner, 1933) he reports a consistent increase in yield of early potatoes on heavy silt loam, mulched just before emergence, over a period of five years both with and without irrigation. The average increase was 13 per cent with irrigation and 25 per cent without. It is perhaps significant that in none of these years was rainfall particularly high. In a discussion of the interaction of mulching and irrigation on potato yields (Werner *et al.*, 1951), it is pointed out that, with irrigation, mulching does not exert much influence on soil temperature during the early period of tuber development because the surface under the plants is generally completely shaded. When the vines are withering, however, and tuber growth is being completed, straw mulching reduces the average temperature around the tubers. Without irrigation straw mulching would exert a greater effect earlier in the season unless large vines were produced owing to optimum weather conditions. In the same paper some observations are made on the effects of these treatments on yield, but unfortunately the data given are not sufficient to allow conclusions to be drawn on the comparative value or interaction of mulching and irrigation. In two seasons when vine growth was checked in July and August by a severe infestation of leaf-hoppers and by a sudden increase in temperature, respectively, both straw mulching and irrigation increased yields, whereas in a third season, when June was very wet and the period from the end of July onwards was warm and dry, irrigation was beneficial but mulching was detrimental except in the case of a variety with a long growing season.

In Iowa, with the same problem of high summer temperatures, Erwin and Rudnick (1922) considered that straw mulching would be

the most practical method of keeping the soil cool. They found that a 6-inch layer of straw reduced the soil temperature at a depth of 7 inches by an average of 4° F. (over a period of six years) and that during heat wave weather in July the difference between covered and uncovered soil was almost 20° F. These figures are comparable to those obtained in Ohio (Bushnell and Welton, 1931), the slightly smaller differences obtained in Iowa being probably due to the fact that readings were taken at a greater depth and that the results are an average of six years instead of a single hot season. In a three-year experiment with potatoes they found that straw mulching increased the yield of marketable tubers by an average of 28 per cent, the greatest increase being in a dry season. The same benefit was obtained in Illinois (Pieper *et al.*, 1930) where potato yields are normally low owing to hot summers and frequent drought. Straw mulching there gave an average increase of 41·6 bushels per acre over a period of four years. In the neighbouring state of Missouri no experimental work is available on the value of mulching for potatoes, although it has apparently been used commercially, for Rosa (1923) mentions that the extensive use of straw mulch in Missouri is restricted to potatoes, and Schroeder *et al.* (1938) say that it has proved successful in some years.

Reports from the northern states are less favourable. In New York State the effects of straw mulching were investigated in six different localities in the exceptionally hot dry season of 1949 (Pratt *et al.*, 1952). In one dryland trial, in Washington county, where only 6 inches of rain fell in the first three months after planting, the difference in yield between the mulched and the cultivated plots was negligible. The authors suggest that under such dry conditions no great saving of soil moisture could be expected from the use of a mulch, as evaporation from a dry soil is low in any case. As no information is given on the type of rainfall, however, the reasons for the ineffectiveness of mulch in this trial must be left unexplained. In trials at the other five localities a significant increase in yield was obtained from mulching without irrigation, but the conditions are not specified in sufficient detail to indicate why the results differed from those obtained in Washington county. In these other five trials mulching and irrigation were used separately and in combination. Each treatment produced a significant increase in yield, though in only one case was the increase from mulching highly significant. The increase due to irrigation was on the average the same on the mulched and unmulched plots, showing that there was no interaction between the two treatments. This is contrary to the evidence of Werner (1929b) who found that irrigation was of more value in cultivated than in straw mulched plots. In both the New York trials and Werner's trials in Nebraska, however, higher yields were obtained from the mulched irrigated plots than from the cultivated irrigated ones, suggesting that the effects of mulch must be attributed to some factor other than the conservation

of moisture. Discussing these results the authors conclude that although mulching may not be important in conserving soil moisture by preventing evaporation in a dry season, it is beneficial in hastening penetration of water into the soil, in reducing run off during hard showers and irrigation, and in maintaining lower soil temperatures.

In a single test in Maine, partly rotted straw applied after the potatoes had been ridged once increased yields considerably (Maine, 1948 ; Terman *et al.*, 1948). The few other reports available from the northern states are all unfavourable. In Rhode Island a straw mulch applied when the plants were 2 inches high reduced yields by an average of 33 bushels per acre over a period of four years (Wessels and Hartwell, 1927). In Montana (Montana, 1915) and Michigan (Harwood, 1893) straw mulching retarded growth and reduced yields.

From countries other than the United States, only a few papers on the straw or hay mulching of potatoes have come to hand, and these all from hot or dry districts. In one popular paper from Israel (Crispin, 1943) it is mentioned that mulching had hitherto only been used in nurseries, but the author recommends the use of straw on potatoes as a safety measure. In that country frequent and efficient irrigation is necessary to ensure good germination, and it is suggested that if straw is applied immediately after planting the danger of poor germination due to insufficient water or uneven ground will be avoided. It is also claimed that a straw mulch will prevent reduction in yield, which is liable to occur if harvesting is delayed and the tubers are exposed to the heat (presumably after the vines have withered). No experimental data are given. In another paper from Israel (Amir, 1948) a small scale trial is reported in which potatoes were mulched with a 20 cm. layer of straw a few days before germination. The yields were similar to those of the cultivated plots but better quality of the tubers and a great saving in amount and frequency of irrigation and labour of weeding are recorded in favour of mulching. In an Indian experiment in the Nilgiris area (Saptharishi and Azariah, 1954) cattle-threshed dry millet straw or chopped dried rushes were used as a mulch on potatoes at the rate of 1,250-10,000 lb. per acre after planting. Significant increases in yield, up to 53 per cent for the early irrigated crop and up to 140 per cent for the second unirrigated crop, were obtained, especially with the heavier rates of mulch application. In this case the soil was porous and deficient in humus and the land was steeply sloping. The great benefit of the mulch lay in protection of the soil surface and prevention of erosion during the monsoons, in conservation of irrigation water during the dry season and in the saving of labour for weeding. In this area millet is usually grown in rotation with potatoes and there is abundant waste straw available. In an article from Colombia (Ernesto Arango, 1948) it is stated that potatoes are sometimes grown under a mulch

in that country and that the system has many advantages in districts with a temperature above 15° C. [presumably average summer temperature]. Details are given of the costs of production, yields and returns of potatoes grown with and without a mulch of " ferns, *Chloris* hay, etc." in 1947. Yields were 75 per cent. higher under the mulch. Quality was also improved with the result that net profits were greatly increased in spite of higher costs of production. The benefits are attributed, without experimental evidence, to conservation of moisture, stabilization of soil temperature and the long term factor of increased organic matter. Dodds and Hawkes (1952) mention that in Colombia and other tropical parts of South America yields of *andigenum* varieties fall progressively with drop in altitude, and are very low at 7,000 ft. unless mulching is practised to reduce soil temperatures ; they will grow quite well at this altitude, however, if mulched in the young stages with dried vegetable refuse such as maize haulms, cut grass or ferns. Finally, straw mulching has recently been tested in Austria as a means of reducing *Colletotrichum* wilt on infected land where the midsummer heat and drought produce large scale outbreaks (Wenzl, 1953). The effect on disease control is dealt with in the section on *Pests and diseases*, but it is relevant to note here that mulching increased yields by 12 per cent in one year and 15·5 per cent in the next.

Briefly summarizing the effects of this practice on yields, it may be said that a cover of straw will tend to be beneficial where temperatures occurring during tuber development are above the optimum and where rainfall during this period is deficient. On poorly drained soils straw mulching will increase the danger of waterlogging in a wet season, while mulching before the soil is warm is likely to reduce yields by retarding nitrification and early growth. The problem of interaction between straw mulching and irrigation appears to require further investigation.

Sawdust. Sawdust, like straw, reduces and stabilizes soil temperatures and tends to conserve moisture ; it has the disadvantage of causing a greater reduction in the nitrate content of the soil. In 1926 trials were started on the value of sawdust and paper mulching, in comparison with cultivation and scraping off the weeds, at the University of Latvia, at a latitude of 56° 30′N. (Apsits, 1931). A 2-3 cm. layer of sawdust reduced the soil temperature but did not, surprisingly, reduce evaporation compared with cultivated soil. Potatoes were used as a test crop for three years and the average yields obtained on the sawdust mulched plots were only 39 per cent of those on the cultivated plots. It is noted that the growth of the potatoes as well as the yield was inferior under sawdust, the detrimental effect being attributed to nitrogen deficiency.

In Russia sawdust mulch also reduced yields of potatoes in a three-year experiment on loam soil (Tamman, 1935). Although the sawdust almost eliminated temperature fluctuation in the soil, it

also reduced gaseous exchange which had a depressing effect on the activity of the aerobic microorganisms in the soil ; this resulted in a low nitrate content.

In America sawdust has occasionally been tested as a mulch for potatoes. In the northern state of Maine (Maine, 1948 ; Terman *et al.*, 1948) sawdust applied either at emergence or after the potatoes had been ridged once decreased yields considerably as a result of reduced penetration of rain water. Under the much warmer conditions of Alabama, on a sandy loam soil, sawdust mulching of late potatoes gave more favourable results (Johnson, 1944). A 3-inch mulch of old pine sawdust increased soil moisture over a period of three years by an average of 2·44 per cent, and maintained a more uniform soil temperature which was higher during cold nights and lower during warm days than that of the cultivated soil. Soil nitrates were not depressed much during the growth of the first crop though they were greatly depressed with succeeding crops owing to the gradual mixing of the sawdust with the soil. Where the same amount of nitrogen (60 lb. per acre) was used on the mulched and the control plots, yields were greatly increased by sawdust in the first year, were about the same in the mulched and control plots in the second year and, rather surprisingly, showed an increase in favour of mulching in the third year. Where extra nitrogen (120 lb. per acre) was given to the mulched plots, the results were complicated by injury caused by the fertilizer in the first two years. This caused the yields to be slightly lower than those obtained from the 60 lb. per acre rate of nitrogen application. In the third year, however, when no injury was caused by the fertilizer, the extra nitrogen was beneficial. The author concludes that sawdust can safely be used as a mulch provided sufficient nitrogen is used. Under these southern conditions it appears to be of considerable value.

In the northwestern United States lumbering is a major industry and wood waste is available in vast quantities. Although the use of wood waste as a mulch has been studied since 1943 in Oregon no experimental work would appear to have been published on its use on potatoes, with the exception of a brief note in the Experiment Station's report (Oregon, 1952) that waste materials such as cedar tow, Douglas fir bark, pine shavings and alder sawdust have given results comparable to Douglas fir sawdust on potatoes. In British Columbia, where sawdust is also readily available as a mulching material, there is also a dearth of information on its use on potatoes. Webster *et al.* (1953) from Saanichton mention that in home gardens all the common vegetables, including potatoes, have done well under sawdust. In a review of the use of sawdust mulch, however, Fletcher *et al.* (1952) from Agassiz state that it is not generally recommended for late season crops like potatoes, although it may be used to advantage with these crops if a later harvest is desired, as sawdust tends to retard maturity. This lack

of interest in potatoes as a subject for sawdust mulching in the lumbering regions of Canada and N.W. America is presumably due to the fact that in those areas high temperatures are not a limiting factor in potato production and the crop is not sufficiently valuable to justify the use of mulching solely for purposes of water conservation or weed control.

Paper. In the extensive series of trials started in America in 1924 on the value of mulch paper for vegetable production, potatoes were frequently included among the crops tested. In almost every case yields were favourably affected. In the first trials, carried out on heavy clay soil in Virginia, unperforated asphalt-coated paper called Thermogen was used and potatoes were grown for three successive years (Flint, 1928). The paper had a consistently favourable effect on yields, the average increase being 162·3 per cent. In these trials the soil temperature increases associated with the use of the black paper were of the order of 10° F. during solar radiation and 3° F. without radiation ; soil moisture in the top 4 inches of soil was also considerably higher under the paper, thus making nutrients in the rich surface layer more available to the crop. The author considers these factors to be mainly responsible for the beneficial effects on yield. In Florida (Florida, 1930, 1932) paper mulch increased the yield of marketable tubers by 124·5 per cent in a year of heavy rainfall and by 44·7 per cent in a dry year. The smaller benefit in the dry year may be due to reduced penetration of rain water through the paper (see also Maine, 1948, and Reinhold and Schmidt, 1930a). In this case the soil temperature was not consistently raised as it was in the Virginia trials, but it was much more uniform under paper, being 5-10° higher at night and 5-10° lower in the daytime. This elimination of extremely high temperatures would seem to be very desirable for potato production in the hot summers of Florida. Work in California (California, 1926a ; Shaw, 1926) throws some light on the apparently contradictory temperature effects of paper mulch. Shaw emphasizes the need for taking continuous temperature records owing to the difference in time lag that occurs between the responses of covered and bare soils. He found that the covered plots were warmer early and late in the season but cooler from the end of May till the middle of July, possibly owing to shading by the plants, and that the average daily range of temperature was only 8·58° F. for the covered plots compared with 11·07° F. for the bare plots. In later trials in California (California, 1929, 1932 ; Smith, 1931) a slight increase in potato yields in two seasons resulted from various types of paper mulch, the greatest effect on soil temperature, soil moisture and crop yield being obtained from complete coverage with unperforated paper. In Ohio the value of paper mulch was tested in 1928 at Wooster (Magruder, 1930) and in the following year at Marietta (Magruder, 1931a and b). In both years there was a dry period during late summer. In the first year there was a slight increase in total yield,

while in the second year about 30 more bushels per acre small tubers were produced under paper, but the marketable yield was not affected. Similarly in Minnesota slight increases in yield were obtained from paper mulching in each of three years, the greatest benefit (20·4 and 24·7 per cent increase) being obtained in a hot dry season (Hutchins, 1933). In Nebraska in a season with two serious drought periods, paper increased yields by 18 per cent on the dryland plots and by 11 per cent with irrigation (Werner, 1933). Temperature measurements taken during 16 days in June and July showed that the temperature of unshaded soil under a paper mulch averaged 2° F. higher than that of cultivated soil and the daily range of temperature was very slightly smaller under paper. The problem arises of why paper mulch, which increased soil temperature, favourably affected potato yields in Nebraska where straw mulches, which reduced soil temperature, have also increased yields. In this connection Werner reports an interesting experiment on the comparative effects of straw and paper mulching on potato yields and soil factors in Nebraska. Over two years straw mulched plots yielded 5 per cent more than paper mulched plots without irrigation and 10 per cent more with irrigation. During June and July the soil temperature under paper averaged 10° F. higher without irrigation and 8·3° F. higher with irrigation than under straw. The average daily range of temperature in June was 3·57° for cultivated soil, 3·21° under paper and 1·4° under straw. The average soil moisture averaged 2·2 per cent lower under paper than under straw both with and without irrigation. Soil nitrates were higher under paper than under straw, but were usually lower than in cultivated soil. It is possible that the more uniform temperature produced by both types of mulch is of greater importance than the actual temperature of the soil. Although the difference in temperature range between paper mulched and bare soil was small in Werner's experiment, other workers have noted a much greater stabilizing effect of paper on soil temperatures (Florida, 1930 ; Shaw, 1926). This point requires further investigation.

In the northern state of Maine, where one might expect the soil-warming effect of paper to have a beneficial effect, heavy paper applied when the potatoes were beginning to emerge reduced yields by about 16 per cent (Maine, 1948). This is attributed to the reduced penetration of rain water, the soil at harvest time being much drier under paper than under mulches of grass or clover. No details are given of soil or weather conditions.

Interest in paper mulching soon spread to Canada, but results with potatoes varied greatly (Agassiz, B.C., 1930, 1931 ; Canada, Div. Hort., 1930b, 1931 ; Fredericton, N.B., 1930 ; Kapuskasing, Ont., 1930 ; La Ferme, Quebec, 1931 ; Morden, Man., 1930, 1938 ; Summerland, B.C., 1930 ; Straight, 1938 ; Woods, 1937). In every case in which the type of paper used is specified, it was the black, asphalt-impregnated paper known as Gator Hide. The

information given in the Experiment Station reports on the effects of paper on soil conditions, etc., is usually insufficient to allow the results to be interpreted. In many cases, however, it is concluded that for standard crops such as potatoes the return per acre did not justify the expenses involved.

At about the same time trials were started in Europe, sometimes with the American asphalt paper, sometimes with home-produced types. In 1926, a very wet year, various tar-free roof-sheetings were tested at Dresden and resulted in a yield increase of 20 per cent for early potatoes and 34 and 13 per cent for late potatoes, depending on variety (Schomerus, 1927). In the same year at Hohenheim a German-manufactured roof-sheeting known as Bitumitekt also gave very considerable yield increases of early potatoes, especially on manured soils (v. Wrangell, 1927). This suggests a better utilization of fertilizers in the covered plots. Moreover, in this very wet season the structure of the heavy loam soil was much better in the covered plots. Another interesting suggestion is made to account for the increased yields, namely that the carbon dioxide emanating from the soil could only escape through the holes around the plants and was thus directed to the places where it would be of greatest benefit. No experimental evidence is given on this point. In the following year, using asphalt paper, v. Wrangell obtained similar increases when the crop was harvested early, but there was little benefit when harvesting was delayed (v. Wrangell, 1929b). He notes, however, that the use of paper for field crops could only become economic if the price were considerably reduced. The paper industry in Germany took up the problem actively and produced a black paper that was relatively cheap and similar to the American asphalt paper in quality. This was known as Natronag. In 1929 trials were carried out with this paper at Grossbeeren on different soil types (Reinhold and Schmidt, 1930a and b). On humus moor soils with a high water table, paper increased the yield of early potatoes by 41·4 per cent, whereas on sandy soils with a low water table the increase was only 7·7 per cent on harrowed land and there was a very slight decrease on ploughed land. It is pointed out that the soil-warming and moisture-conserving effects of paper are much more apparent on humus soils than mineral soils. Part of the rain water evaporated off the paper before it could reach the soil, so that sandy soils with a low water table were drier as a result of covering ; humus soils with a high water table, however, are not dependent on rain for their water supply and the reduced evaporation due to paper thus had a favourable effect on moisture conservation. In a manurial trial on humus soil the yield increases due to paper were not higher on plots given a complete NPK fertilizer than on unfertilized plots, but they were slightly higher on plots given only NP, NK or PK.

In France paper mulching of potatoes has not generally given very promising results, although in the first trial at Versailles, in

which bituminous paper was used on sandy soil during a dry summer, yields of early and late varieties were increased by an average of 65 per cent (Ducomet, 1927). In trials in 1929 in which a French paper was used on a variety of crops, including potatoes, the results were all negative or inconclusive (de Marcillac, 1930). In the following year, which was very wet, Thermogen paper was tested at Versailles, and mulching reduced potato yields by 6·5 per cent (Petit, 1931). The soil was deep with a good water-retaining capacity and it is considered that on this soil paper mulching accentuated the harmful effects of the wet season, and that it would only be of value in a season with long periods of heat and drought. Other experiments at Versailles on silt soil are reported by Servy (1933). In the same exceptionally wet season of 1930, one type of American paper increased yields by 10 per cent while another type gave no increase, the soil humidity under the paper being too high. The next year yields were increased 20 per cent by the American papers and 38 per cent by a French paper impregnated with fertilizers. In 1932 the French paper caused a 73 per cent yield increase, but even this was not considered sufficient to cover costs. It is concluded that summer droughts are not generally long enough in France for paper to have its full beneficial effects on yields. Even in the Mediterranean districts, where the longest periods of summer drought occur, yields of early potatoes were only increased by 21 per cent and paper mulching was not considered economic (Boischot and Albert, 1931).

In two trials in Czechoslovakia (Boresch, 1932 ; Lerch, 1930), one in Latvia (Apsits, 1931) and one in Denmark (Gleie, 1926) only small increases in potato yields are recorded as a result of paper mulching.

Some of the results of Russian work on paper mulching carried out at the Institute of Potato Economy are reviewed by Tamman (1935). The effects have been very variable. On the heavy loam soils of Leningrad and Sverdlovsk yields of early potatoes were increased by about 50 per cent in 1932 whereas in 1933 mulching was detrimental. On the degraded chernozem soil at Uljanov yields were decreased in one year and increased by 20-25 per cent the following year. At the Institute itself, on light sandy chernozem soil, yield increases were 27 per cent in the dry season of 1932, 15 per cent in 1933 with a wet spring and dry August, and only 5 per cent in 1934 with a dry spring and a wet summer. It is concluded that the positive effects of paper mulching are most apparent in regions with heavy soils and adequate rainfall, as such soils benefit greatly from increased temperatures. Relatively good results have also been obtained in the chernozem areas as a result of the moisture-conserving action of the mulch.

Other materials. Straw and sawdust are only cheap and plentiful in certain districts. Emerson, in Nebraska, states that any coarse waste material that is free from weed or grain seed, holds

moisture, suppresses weeds and keeps the soil cool can be used (Emerson, 1914). He found that a 4-inch mulch of coarse stable manure applied after planting increased yields by 29 per cent (Emerson, 1903). This test was made in a very wet season when straw applied in the same manner was detrimental. Manure, however, is usually expensive, which probably accounts for lack of experimental work on its value as a mulching material. In a single test in Yugoslavia it gave very good results, increasing yields of dryland, early potatoes by about 27 per cent (Drezgić, 1953). There was little difference between the effects of half-fermented and fermented manures. The author, however, does not consider its use economic owing to the scarcity of manure and the large quantities required for mulching. In the same tests a 5 cm. deep mulch of chaff gave even better results than manure. Workers at the Maine Experiment Station suggest that light mulching of potatoes with mulch material grown on the poorer sloping land provides a means of maintaining organic matter on the better, more level land so that potatoes can be grown there every year (Maine, 1948 ; Terman *et al.*, 1948). In one test unchopped green grass and green clover mulches, applied when the potatoes were emerging, increased yields slightly. In a second test these materials applied after the potatoes had been ridged once increased yields considerably. Extra nitrogen fertilizer broadcast with the mulch at the rate of 60 lb. per acre further increased the yield of potatoes mulched with grass but not of those mulched with clover. It was found, however, that it would be necessary to chop the material to prevent trouble at harvest time.

Some interesting work has been done recently by the Rostov State University on the effect of mulching on the highly saline solonchak soil of the Azov-Don basin (Karnauhov, 1949). Potatoes grown on this soil were mulched with a 6-8 cm. deep layer of freshly cut reeds immediately after planting. The reeds had a temperature-reducing and moisture-conserving effect similar to that of a straw mulch. For instance when the temperature on the surface of the bare soil reached a maximum of 45·5° C. that of the covered soil was only 27·5° C., and the temperature range on the surface of the covered soil was only 8·9° C. compared with 26·2° C. for the bare soil. Soil moisture ranged from 14·5 to 19·2 per cent in the upper 5 inches of the bare soil and from 36·1 to 40·8 per cent in the covered soil. This increase in moisture content resulted in the leaching out of soluble salts, especially sodium chloride, from the root zone so that normal plant growth was made possible. Moreover, mulching had the additional effect of increasing the nutrient content of the soil to a depth of 10 cm., NO_3 being increased by 15-40 mg. and P_2O_5 by 1·6-2·1 mg./kg. soil. It was considered that this improvement of the nutrient regime increased the salt tolerance of the plants. The effect of these soil changes on yield were phenomenal, the total weight of tubers per plant being increased

nearly 9-fold, i.e. from 86 g. to 740 g. This increase was due largely to the fact that the unmulched plants suffered severely from the high concentration of salts in the soil, the plants being small with yellowish, dry leaves and dying roots. The author points out that reduced temperatures at time of tuber formation and an improved nutrient and water regime are of relatively less importance than a reduction in salt concentration, since on the non-saline steppe soils of the Rostov area only a 30-40 per cent. increase in potato yields had been obtained as a result of mulching. On the basis of this experiment, mulching appears to be a most promising method of bringing apparently unfertile saline soils into a productive state.

Two other types of mulch have been tested on potatoes, Wega mulch in Germany and aluminium foil in America. Wega mulch is a black, impregnated woodwool with a particle size of 2 mm. This has an insulating effect, reducing temperature variation in the soil and preventing evaporation. In a single trial potato yields were increased very slightly by Wega mulch but its use was not considered economic (Reinhold, 1942). The use of aluminium foil as a mulch has been developed in America within the last few years. Extensive tests with a number of vegetables were made in Virginia in 1949 (Wall, 1950). In addition to its moisture-conserving action, aluminium foil has great light-reflecting properties, with the result that the soil temperature at a depth of 3 inches was 20° lower in the warm part of the day and 8° higher during cool nights than in unmulched soil. Potatoes benefited considerably from this more stable temperature and moisture, and mulching increased yields by 46 per cent. No details of soil or weather are given and there is no information on the economics of foil mulching.

On growth and maturity

If straw mulch is applied too early in the season, before the soil has warmed up, it is likely that the rate of nitrification will be reduced and germination and early growth of the plants retarded. In two seasons in Ohio, mulching at planting time delayed emergence and, in a very wet cold season, reduced the stand and retarded ripening by three weeks with the result that yields were reduced (Ohio, 1883, 1884). In a year when conditions at planting time were favourable for growth, however, mulching had no effect on time of ripening and yields were increased (Ohio, 1885). Bushnell and Weaver (1930) observed that early potatoes mulched at planting time emerged later, grew more slowly and were lighter green in colour, presumably a nitrogen effect, but that they later recovered. Retardation of early growth was also noted by Emerson (1903) and Harwood (1893). Provided the soil is not kept too cool in the early part of the season, however, and summer temperatures are high, the cooling, moisture-conserving effect of straw may prolong the growing season with advantage (Bushnell and Welton, 1931 ; Emerson, 1903 ; Ernesto Arango, 1948 ; Werner, 1929b ; Werner

et al., 1951). In Colombia the growing season was prolonged by as much as two months by a mulch of *Chloris* hay and ferns (Ernesto Arango, 1948).

Apsits (1931) and Tamman (1935) noted poor development of potatoes grown under a sawdust mulch. This they attributed to nitrogen deficiency which could, presumably, be avoided by proper fertilizer treatment. Fletcher *et al.* (1952) warn growers that sawdust will delay maturity of late season crops like potatoes.

Paper mulching on the other hand tends to hasten germination, early growth and maturity. Earlier germination under paper has been noted by several authors (Gleie, 1926 ; Hutchins, 1933; Magruder, 1930, 1931a ; Morden, Man., 1930 ; v. Wrangell, 1927), as has more vigorous vegetative growth and earlier flowering (Canada, Div. Hort., 1930b, 1931 ; Flint, 1928 ; Gleie, 1926 ; Hutchins, 1933 ; Lerch, 1930 ; Magruder, 1930 ; Werner, 1933 ; v. Wrangell, 1927). From the economic point of view, however, the time of ripening is the most important factor, for unless paper mulching makes it possible for the crop to be marketed much earlier than normally and thus command a higher price the cost will be too high to justify the practice. Earlier ripening as a result of warmer soil conditions under paper has been reported by several workers in various parts of the world (Gleie, 1926 ; Lerch, 1930 ; Morden, Man., 1930 ; Reinhold and Schmidt, 1930a ; Werner, 1933 ; Woods, 1937). On the other hand, Magruder (1931a) in Ohio and Boischot and Albert (1931) in France found that paper mulching made no difference to the time of maturity, while Smith (1931) in California found that in one year out of two maturity was retarded owing to prolongation of the growing season. These contradictory findings have not been adequately explained. The explanation may lie in the variation of soil and weather conditions, for where the moisture-conserving action of paper exerts the greatest effect the vigour and growing season of the crop will be prolonged, and where the soil-warming action is dominant the growth cycle will be speeded up. It is clear, however, that paper mulching cannot be relied upon to increase earliness.

In the single test with aluminium foil for potatoes it was found that the vines on the mulched plots made more rapid growth and stayed green longer, with the result that the plants had an extra 10 days' growth before harvest and produced larger tubers and heavier yields (Wall, 1950).

Striking growth differences were observed in potatoes grown on saline soil in Russia as a result of mulching with reeds (Karnauhov, 1949), but these can be attributed largely to the reduced salt content of the soil [see p. 80].

It has sometimes been observed that mulched potatoes produce tubers at or near the soil surface ; this, of course, would facilitate harvesting. Woods (1956) reports that under a sawdust mulch the tubers are invariably formed at the soil surface with only the roots

penetrating the soil. Erwin and Rudnick (1922) mention that strawed potatoes develop nearer the surface, but that as the tubers are generally larger than unmulched ones it is necessary to dig to the same depth at harvest. In plots completely covered with unperforated paper about 5 per cent of the crop was found on the soil directly under the paper ; this did not occur with perforated paper or partial coverage (Smith, 1931). Straight (1938) and Apsits (1931), however, found that the tubers were produced almost entirely on the surface of the soil under paper ; as they enlarged they pushed the paper up and tore it, thus becoming exposed to sunlight.

On quality and composition

One marked effect of mulching which has frequently been observed, irrespective of the type of material used, is an improvement in size of tubers (Drezgić, 1953 ; Emerson, 1903 ; Ernesto Arango, 1948 ; Erwin and Rudnick, 1922 ; Flint, 1928 ; Florida, 1932 ; Karnauhov, 1949 ; Ohio, 1884 ; Pratt *et al.*, 1952 ; Wall, 1950 ; Waugh, 1895 ; Wenzl, 1953 ; Werner, 1929b, 1933). This is presumably due to the better moisture regime under mulch which allows the tubers to make continuous unimpeded growth. The only report in which it is positively stated that mulching had no consistent effect on tuber size is one from Latvia when paper and sawdust were used (Apsits, 1931). In some cases (Karnauhov, 1949 ; Pratt *et al.*, 1952) increase in tuber size was entirely responsible for the higher yields, mulching having no effect on the number of tubers set. Quite apart from its effect on yield, however, the tendency of mulching to increase the percentage of prime tubers and reduce the number of culls is a factor to be considered.

The more constant supply of soil water under a mulch is responsible for another beneficial effect on quality, the reduction or elimination of secondary growth. Certain varieties tend to produce abnormal secondary growth in seasons when a dry period, which interrupts development of the tubers, is followed by rain, or when sharp temperature fluctuations occur. Greater or complete freedom from secondary growth as a result of mulching, especially in dry seasons, is reported by several authors (Amir, 1948 ; Bushnell and Welton, 1931 ; Erwin and Rudnick, 1922 ; Tamman, 1935 ; Werner, 1933). This effect is not quite consistent, however, for in experiments in New York State Pratt *et al.* (1952) report a slight increase in growth defects in one trial and a slight decrease in another. No explanation is given of this anomaly.

Appearance of the tubers has been affected by mulching in various other ways. Emerson (1903) noted that straw mulched tubers were smoother except on irrigated land, when they were rough and watery as a result of the soil being too wet while they were maturing. Later he attributes the smooth skin of mulched tubers to lack of drying out and states that the smoothness does not

indicate lack of maturity and poor cooking quality as it would with tubers grown in cultivated soil ; on exposure to air during storage the skin developed a normal corky appearance (Emerson, 1907). In another case excess of moisture under straw in a wet year caused enlarged lenticels (Bushnell and Welton, 1931). Improved shape, more typical of the variety, is noted as a result of straw mulching (Amir, 1948) and reed mulching on saline soil (Karnauhov, 1949). Smith (1931) found that potatoes grown at higher temperatures, such as were produced by a black paper mulch, were more elongated than those grown at the lower temperatures of the cultivated plots. That this is a temperature effect is corroborated by the experiments of Werner (1929a) who grew Triumph potatoes under controlled temperature conditions and found that those grown at 55-65° F. were almost round in shape whereas those grown at 75-85° F. were more elongated. Werner also found that the low-temperature tubers were generally quite firm while the high-temperature tubers were sometimes soft or spongy ; Smith, however, found no difference in the firmness of paper-mulched and unmulched tubers. Another temperature effect noted by Werner was the more intense colour of the red-skinned varieties grown under low temperatures ; in a later experiment on straw mulching (Werner, 1933) this deeper red colour was noticed on the mulched tubers.

Where mulching improves the texture and friability of the soil it is likely that the potatoes will be harvested more cleanly and with a low percentage of dirt. This effect was especially noticeable on irrigated land under a straw mulch (Amir, 1948) and in a very wet season on heavy soil under a paper mulch (v. Wrangell, 1927).

Cooking quality, in America at least, is judged by the mealiness of the tubers, the more mealy the tubers the better the quality. A high starch content and a high starch: protein ratio is responsible for mealiness. Specific gravity is often used as an index of quality. Pieper *et al.* (1930) report that straw mulching improved the culinary quality of potatoes, the tubers being mealy and having a good flavour ; no details are given of their composition or of the factors responsible for this improvement. More light is thrown on the problem, however, by Werner (1929b, 1933). He gives figures showing that straw mulching markedly increases the percentage starch and decreases the percentage protein and sugars. In unirrigated plots the starch was increased by 3·2 per cent and the starch: protein ratio from 3·51:1 to 5·51:1 ; in irrigated plots the increases were 2·3 per cent and from 4·85:1 to 7·36:1 respectively. Although the ratio was higher in the irrigated than the dryland plots even without mulch, it seems that the effect is not solely due to soil moisture, since irrigation alone decreased the percentage starch as well as the percentage protein and sugars. In a series of experiments in New York straw mulching resulted in a small but highly significant increase in specific gravity (mulch 1·069, no mulch 1·067) while inconsistent results were obtained from

irrigation (Pratt *et al.*, 1952). With paper mulching results are even more complicated. In Russia the starch content of tubers was usually reduced by 1·0-1·5 per cent, except in a year with a dry spring and wet summer when paper mulching increased the starch percentage slightly (Tamman, 1935). In Germany, in a very wet year when paper mulching increased yields considerably, starch content was only slightly increased, by 0·1 per cent on unmanured soil and 0·2 per cent on manured soil (v. Wrangell, 1927). Reinhold and Schmidt (1930a) put forward the theory that the starch content is increased by conditions that increase yield. These workers found that on humus soil, where paper gave large yield increases, starch content determined by the specific gravity method was increased by 1·0 per cent on unmanured plots and 1·24 per cent on plots given a complete fertilizer ; whereas on sandy soil, where paper mulching was slightly detrimental to yield, starch content was decreased by 1·43 per cent. These results are all empirical and no fundamental work appears to have been done on the environmental factors responsible for good cooking quality.

A final but important point to be considered in connection with the quality of potatoes is ascorbic acid content. Werner *et al.* (1946, 1951) have studied this question in great detail in Nebraska in relation to the effect of straw mulching and irrigation. These experiments showed that straw-mulched tubers had significantly higher reduced ascorbic acid values at and after the period of maximum plant growth than cultivated tubers, the average increase for three varieties over three years being 11 per cent. Straw mulching had no effect on ascorbic acid content in the early stages of plant development, but by prolonging the growth season and shading the tubers it retarded loss of ascorbic acid towards the end of the season. Moreover, straw mulched tubers had higher ascorbic acid values throughout the storage period than cultivated tubers. That this is not a soil moisture effect is shown by the fact that irrigation sometimes decreased ascorbic acid content slightly. A positive correlation was found between ascorbic acid content and specific gravity (or dry matter content) of tubers on growing plants, although with the death of the vines ascorbic acid decreased much more rapidly than did the specific gravity. Specific gravity tended to decrease when soil moisture was high, a fact which might account for the slightly lower ascorbic acid values of irrigated tubers. High temperatures during the period of vine senility also caused a reduction in specific gravity, probably because of tuber respiration and resorption of material into the dying plant, and this explains to some extent the favourable effect of straw mulch on the ascorbic acid values of tubers late in the season. There appears to be no other work directly on the effect of mulching on ascorbic acid content of potatoes, but the correlation found by Werner between ascorbic acid content and specific gravity makes it possible to link up this problem with the effect of mulching on starch content, discussed in

the preceding paragraph. It is important to remember, however, that the correlation was only found in tubers taken from the living plant. Although Wokes and Nunn (1948) present data which suggest a possible relationship between total solids and vitamin C content in stored potatoes, Murphy *et al.* (1945) found no correlation between starch content and ascorbic acid content of tubers stored for 3-4 weeks. Until a fundamental study is made of the environmental factors responsible for good cooking quality and high vitamin content, it will not be possible to explain satisfactorily the effects of mulching on this important aspect of production.

On pests and diseases

During a series of investigations on the influence of environmental factors on the quality of seed potatoes Werner (1929b) found that degeneration of seed stock in Nebraska due to spindle tuber virus infection could be prevented by growing the seed crop under a straw mulch. On the basis of plant top symptoms at the end of June, potatoes planted on 10 April showed a mean spindle tuber coefficient of 9·43 in the cultivated plots and 3·0 in the straw-mulched plots ; for potatoes planted on 18 May the coefficients were 8·93 and 1·67 respectively. The reason for this great difference in degree of infection between cultivated and mulched plants was not certain, but Werner points out that it may be due to a difference in time of infection or in rate of spread of the virus within the plant, to less extensive transmission under mulch, or to greater symptom masking. The value of a mulch in preventing degeneration of seed potatoes is discussed more fully in the section on *Quality of seed potatoes*.

Wenzl (1953), working in Austria, has recently shown that *Colletotrichum* wilt of potatoes can be satisfactorily controlled by straw mulching. Previous work had indicated that the wilt was generally related to deterioration of soil structure causing a disturbed water supply, and it was thought that crops could only be grown on infected land by using early varieties and harvesting before the midsummer heat and drought produced large scale outbreaks of wilt. Trials were started in 1950 in the wilt disease area east of Vienna to determine the effect of mulching with short (20-30 cm. long) straw after earthing up ; 70-80 kg. straw per 100 m^2 were used. Straw reduced the number of soft, wilt-infected tubers from 0·9 per cent to 0·19 per cent in one year and from 9·9 per cent to 5·3 per cent in the next. Non-parasitic drying of the leaves was also much more evident on the control plots. It was considered that the favourable effect of mulching in this drought area was due to improvement of soil structure and conservation of water, and that even better control of *Colletotrichum* might have been obtained by a heavier and earlier application of straw.

No other fundamental work appears to have been done on the effect of mulching on incidence of pests and diseases of potatoes, all

the information available being the result of incidental observations made during the course of general mulching experiments. Emerson (1903) observed that potatoes mulched with coarse stable manure were more seriously injured by scab than those mulched with straw. Later he states, without giving experimental evidence, that tubers formed on the surface of the ground under a mulch are distinctly more liable to scab than those that are well covered with soil (Emerson, 1914). Werner (1933) mentions that straw mulching greatly reduced the percentage of common scab. In a paper from Colombia (Ernesto Arango, 1948) the rather vague statement is made that mulched potatoes are less seriously attacked by pests and diseases, especially *Epitrix*. Straw mulched plants in Nebraska recovered better from a severe leaf-hopper attack than unmulched plants (Werner *et al.*, 1951). Moles caused considerable damage under a straw mulch in Palestine (Amir, 1948). Krüger (1952) also noted that moles and mice were attracted to the straw covered plots because of the greater number of earthworms, on which they feed, in the upper layers of the soil. v. Wrangell (1927) observed that moles did not seem to burrow under a paper mulch (possibly because they could not reach the surface) but that in a wet season large numbers of mice were found under the paper covering the potato crop. In the Nilgiris district of India, where the monsoon rains cause serious soil erosion and expose the tubers to the depredations of rodents and to tuber moth attack, considerable protection was found to be given by straw and reed mulches (Saptharishi and Azariah, 1954).

On harvesting

When potatoes are grown in a hot climate a delay in harvesting may result in considerable loss from the tubers being exposed to the sun after the haulms have withered. By shading the tubers, mulching will prevent such loss and the crop may be harvested when convenient. Crispin (1943) puts this forward as one of the chief points in favour of mulching potatoes in Palestine, and Hayter (1955) mentions that grass and slashed weeds have been used with good effect in southern Rhodesia as a mulch on mature potatoes to reduce soil temperatures pending lifting for market. In Oklahoma it was found that early potatoes grown under a straw mulch could be left in the ground until autumn with very little loss from rotting, whereas unmulched crops had to be harvested as soon as they were mature, and even so suffered severe loss in storage (Morris, 1901). The ascorbic acid content of potatoes left in the ground throughout the autumn is, moreover, very much higher in straw-mulched fields than in cultivated fields ; in fact, in straw-mulched tubers it is even higher than in tubers harvested when nearly mature and stored in a cellar (Werner *et al.*, 1951). Thus under a straw mulch harvesting may be delayed without detriment to the crop and in some cases even with advantage.

On the other hand, mulching may complicate the process of harvesting. It is difficult to use a digger unless most of the straw is removed and the removal of wet, matted straw is not an easy task (Bushnell and Weaver, 1930 ; Erwin and Rudnick, 1922). Erwin and Rudnick (1922) go so far as to say that the labour saved in cultivation is spent in harvesting. Recent tests in Austria (Wenzl, 1953), however, have shown that if the straw is chopped into 20-30 cm. lengths before application machine harvesting is not impeded ; on the contrary it was facilitated because the mulched soil was open and crumbly whereas the uncovered soil had become hard by harvest time. Greater ease of harvesting as a result of improved soil sonditions has also been claimed as an advantage of paper mulching, especially in wet seasons (v. Wrangell, 1927). Unchopped green grass and green clover mulches, however, have given trouble at harvest time and it is recommended that these materials should be chopped before use (Maine, 1948).

It has sometimes been observed that when potatoes are grown under a mulch the tubers develop near or on the surface of the soil (Erwin and Rudnick, 1922 ; Smith, 1931 ; Straight, 1938 ; Woods, 1956). Although Straight observed that little digging was necessary under a paper mulch, and Woods claims that sawdust mulched potatoes can be dug by hand, Erwin and Rudnick found that although the tubers were nearer the surface under straw they were usually larger and it was therefore necessary to dig to the same depth as usual.

On storage quality

There has been surprisingly little work done on the effect of mulching on the storage quality of potatoes. One interesting series of trials was carried out in Oklahoma (Morris, 1901) where summer temperatures are so high that mid-season and late crops of early potatoes are generally poor and the problem of keeping early potatoes for winter use is an important one. Losses during storage in a cave were high, so a comparison was made of several methods of keeping the early crop in the soil until autumn : (1) leaving it undisturbed in level, cultivated soil ; (2) ridging after maturity ; (3) sowing a covercrop of cowpeas just before maturity to reduce moisture and shade the potatoes ; (4) mulching with straw or old hay in spring or summer. Mulching proved to be by far the best method. In two seasons the loss due to rotting was only 5 per cent and 15 per cent respectively under the mulch compared with 20-80 per cent with the other methods. As many bushels were dug from the mulched plots in autumn as were dug from the cultivated plots at time of maturity, so storage losses were virtually eliminated. Moreover the condition of tubers kept in the soil under a mulch was better than that of tubers stored in a cave. This method of keeping potatoes, however, is not likely to have a wide

application and it is of more value to know the effect of mulching on potatoes kept normally in store.

In a report on straw mulching experiments in Nebraska it is noted in passing that in one year irrigated mulched potatoes did not keep so well as unirrigated or cultivated potatoes because the soil was too wet during the period of ripening with the result that the tubers were rough and watery (Emerson, 1903). On the other hand in a cool, rather dry season in Ohio potatoes from cultivated soil wilted and sprouted earlier in storage than those from mulched soil, while even in a year when September and October were exceptionally wet the mulched tubers remained firm longer (Bushnell and Welton, 1931).

In the recent American work on the vitamin C content of potatoes (Werner *et al.*, 1951) it was shown that straw mulched tubers not only had higher ascorbic acid values than cultivated tubers but that this superiority persisted throughout the whole storage period. The mean ascorbic acid content of straw mulched tubers for 10 weeks of autumn storage was 26 per cent greater than that of cultivated tubers, while the values for winter storage were 10·4 mg. ascorbic acid per 100 g. fresh weight for straw mulched tubers and 8·9 mg. for cultivated tubers.

On quality of seed potatoes

In many of the central and southern states of the U.S.A., where summer temperatures are high, it is common practice to import seed potatoes from the north since home-grown stocks usually degenerate rapidly and become progressively less productive. Straw mulching, however, has proved a very successful method of maintaining productivity in the warmer states. The first work on the value of mulching for seed potatoes was carried out at Lincoln, Nebraska, by Emerson (1907). When seed stock was grown under a straw mulch in 1904 and 1905, the yields obtained in the following years, without mulch, were 47 and 41 per cent higher respectively than those obtained from seed produced by normal cultivation methods. Further and more extensive experiments confirmed those results (Emerson, 1914). When northern-produced seed stock was grown at Lincoln in 10 separate trials, with and without straw mulch, the average yield the following year showed an increase of 46·6 per cent in favour of mulch. Various tests indicated that this great difference in productivity between continuously cultivated and continuously mulched stocks was due to the gradual deterioration of the cultivated stocks and not to the improvement of the mulched ones, as stocks cultivated for several successive years were less productive than those cultivated for only one year, whereas stocks mulched for several years were no more productive than those mulched for only one year. Mulching was therefore a means of maintaining the original productivity of stocks imported from the northern states. A further series of tests showed that a single

year's mulching could restore the vigour of degenerated stocks ; for example, stocks cultivated for six years and then mulched for one year were as productive as those that had been mulched continuously for seven years. Viewed in the light of future work, this is a rather surprising result and it has not been adequately explained. As regards the type of mulching material, there was little difference in the effectiveness of wheat straw, strawy horse manure and strawy cow manure, and it is concluded that any coarse waste material that is free from weed and grain seed, holds moisture, keeps down weeds and keeps the soil cool can be used, but that on very sandy soils or soils lacking in fertility stable manure would be preferable to straw. Mulching was only effective if it was carried out before the tubers began to develop. In discussing the practical value of these experiments Emerson considers that, provided waste straw or hay is available, good quality seed potatoes can be produced more cheaply locally in Nebraska by means of mulching than they can be imported ; moreover for breeding purposes it is essential to produce strong stocks locally that can be maintained in vigour for a long period. He offers no explanation, however, to account for these beneficial effects of mulching.

In support of Emerson's findings there is a report from Illinois, with no experimental evidence however, stating that for seed purposes mulched potatoes are about equal to northern-grown potatoes (Pieper *et al.*, 1930). Results of a 4-year trial in Rhode Island with northern grown stock also showed that, although straw mulching slightly reduced the yield of the current crop, the seed tubers produced on the mulched plots were more productive the following year than those from the unmulched plots (Wessels and Hartwell, 1927). Neither of these reports gives reasons for the superior vigour of mulched seed stock.

The first paper in which an attempt is made to analyse the factors responsible is a report by Werner (1929b) of experiments carried out in Nebraska after it had been recognized that degeneration was due to the presence and spread of virus diseases. In these experiments spindle tuber was the only virus disease of any consequence present. When spindle tuber was not present, seed did not degenerate to any significant extent and cultural treatments had little effect on subsequent yields. In a 4-year trial straw mulched seed stock was consistently more productive than unmulched and the incidence of spindle tuber infection was lower. It is considered that conditions under the mulch were less favourable to the spread of the disease. As mulching was more effective with the early plantings, when maximum tuber development coincided with the hot weather in July, than with later plantings, when tubers developed mainly in the cooler autumn months, it seems probable that the effect is a temperature one. It does not appear to be due to increased soil moisture, since irrigation of the seed stock had little effect on the productiveness of the tubers, although it increased

yields of the current crop. Another possible explanation of the less rapid spread of spindle tuber under mulch is the reduced nitrate content of the soil. In a single test no evident correlation was found between soil nitrate content and productivity of seed tubers, but in this test no spindle tuber was apparent in any of the plots. In this connection Werner quotes the evidence of J. J. Janssen (*Tijdschr. PlZiekt.*, 1929, 35: 119-51) that the aphids responsible for mosaic and leaf roll infection of potatoes increased most rapidly on potassium deficient plants and least rapidly on nitrogen deficient plants. Whether the same applies to the vectors of spindle tuber does not appear to have been investigated. These trials by Werner also showed that, contrary to the evidence of Emerson (1914), straw mulching of potatoes heavily infected with spindle tuber did not rejuvenate the stock nor did it reduce the amount of infection. This finding is in accordance with the theory that mulching merely retards the rate of spread of virus, but Emerson's results still remain unexplained.

An interesting suggestion has been put forward recently by Woods (1956) that the lesser maturity of mulched or northern-grown seed tubers, in comparison with unmulched tubers grown in the southern states, may be responsible for their greater productivity. In support of this theory he cites the results of his own experiment (unpublished data) in which seed potatoes dug early in the season invariably gave a better crop the following year than those dug later.

Technique of Mulching

Time of mulching

Reports show that organic mulches of such materials as straw and manure have been applied at various stages of the crop's development, ranging from immediately after planting to late summer. Owing to the incomplete nature of some of the data it is difficult to draw detailed conclusions on the effects of time of mulching from a survey of all the experiments, but in general it appears that mulching just before or after emergence has more often proved beneficial than mulching at time of planting. The few experiments made specifically to determine the best time to apply mulch have also shown that mulching too early in the year may have undesirable effects. Emerson (1903) made tests on early potatoes in a wet season in Nebraska. Mulching with a 4-inch layer of straw at time of planting reduced yields by 11 per cent, whereas when application was delayed until late summer yields were increased by 11 per cent. A similar layer of coarse stable manure, however, applied at planting, did not have this detrimental effect ; in fact yields were increased by 29 per cent in comparison with the unmulched plots. Why manure should be safer to use early in the season than straw is not explained, but Emerson concludes that straw mulching should be delayed until the soil has warmed up to

prevent retardation of early growth. After a further four years' work he confirms this conclusion (Emerson, 1907), and states that, although potatoes can be mulched as soon as they are planted, better results are obtained from mulching just before emergence after one or two harrowings. The best results of all, from the point of view of yield, were obtained from mulching when the plants were several inches high, but in practice this proved too expensive. Although the shoots are able to push through a 4-inch layer of straw if this is applied before emergence, the plants may be killed or weakened if the shoots are covered after the leaves have expanded. Similar results were obtained from experiments in Ohio (Bushnell and Weaver, 1930 ; Bushnell and Welton, 1931). In each of two years early potatoes, planted about 1 April, were mulched (*a*) at planting, (*b*) just after emergence, and (*c*) when the soil had reached a temperature of about 65° F., i.e. when the plants were about 12 inches high. The early mulch retarded early growth in both seasons and the plants showed typical symptoms of nitrogen deficiency ; in one year the yield was reduced below that of the cultivated plot, in the next year it was slightly higher. The second mulch gave the highest yields in both seasons. Yields from the late mulched plots were higher than those mulched at planting but lower than those mulched at emergence, partly owing to the fact that many leaves were unavoidably covered or broken during the application of the straw. The conclusion is again drawn that early potatoes should not be mulched too early.

It is clear that the ill effects of early mulching would be most serious in a cold or wet spring and on heavy soil. In Israel, where hot dry weather during the potato planting season appears to be a problem, application of straw immediately after planting is recommended (Crispin, 1943). It is stated that for good germination potatoes require frequent and systematic irrigation, and that where this is impossible mulching will help to prevent irregular germination. No experimental work, however, would appear to have been carried out in Israel on time of mulching potatoes.

In the case of seed potatoes, an experiment in Nebraska showed that mulching is only effective in preventing degeneration if the seed stock is mulched before the tubers have begun to develop (Emerson, 1914).

Paper mulch is usually applied at time of planting. Either drills are opened along the side of a strip of paper and the tubers planted before the next strip is laid (Canada, Div. Hort., 1930b), or the tubers are planted through holes in the paper (Magruder, 1931a). Occasionally the paper has been laid after planting and holes have been pierced in it to allow the shoots to come through (Maksimova, 1935 ; Servy, 1933). In some cases, however, the paper was laid after the potatoes were up, and was fitted round the plants (Shaw, 1926 ; Smith, 1931). There appears to be no experimental work on the best time or method of application.

Depth of mulch

The task of comparing the results of experiments by different workers in order to determine the effects of depth of mulch is made very difficult by the fact that many workers do not state whether their figures refer to the depth of mulch at application or that after settling. According to Bushnell and Welton (1931), straw applied at the rate of 10 tons per acre gives a layer of about 8-10 inches deep when first spread, which packs to one of about 4 inches deep after settling. Emerson (1907), on the other hand, states that an application of 15-20 tons per acre is required to give a 4-inch layer after settling.

In the various straw mulching experiments studied the depth of mulch used covers quite a wide range. The lowest rate of application was only 2 tons per acre (Pratt *et al.*, 1952); this was used in a very dry season in New York State and resulted in a slight increase in yield, but no observations were made on its weed control value. In Nebraska a layer of 2 inches deep (presumably after settling) was effective not only in increasing yields in four seasons out of five, but also in preventing degeneration of seed stock ; again weed control is not mentioned (Werner, 1929b). A thick layer of straw, 6 inches deep when settled, also gave good results over a three year period in Iowa (Erwin and Rudnick, 1922).

When various depths have been compared experimentally, a layer 4 inches deep after settling has usually given the best results. Emerson (1903) found that the detrimental effects of mulching at planting time in a wet season were less pronounced with a 4-inch mulch (11 per cent decrease) than with an 8-inch mulch (34 per cent decrease). From a later series of experiments (Emerson, 1907) he concludes that a layer 4 inches deep after settling keeps down weeds and conserves moisture as well as thorough cultivation and that a deeper mulch is not only unnecessary but may be detrimental. The plants will readily penetrate a 4-inch mulch applied before emergence provided large seed pieces are used, but they may fail to penetrate an 8-inch mulch. Bushnell and Welton (1931) carried out a trial over two seasons in which straw was applied to potatoes at rates varying from 4 to 10 tons per acre (10 tons giving a 4-inch layer when settled). In each year the highest yield was obtained from the heaviest mulch. It was noted that annual weeds readily penetrated the straw when less than 10 tons per acre were used. Previously Bushnell and Weaver (1930) had observed that even 10 tons per acre would not keep down perennial weeds such as thistle and morning glory, and they recommend that where such weeds are present a straw mulch should not be used.

When chaff was used as a mulch for potatoes in a very dry season, the yield increase obtained from a 5 cm. layer was almost twice that obtained from a 10 cm. layer (Drezgić, 1953). This is attributed to the fact that the deeper mulch absorbed more rain water with the result that the underlying soil was drier.

Depth and distance of planting

Usually straw mulched potatoes are planted at the normal depth. In some cases, however, when mulch has been applied at planting time, the tubers were covered with only a very thin layer of soil (Ohio, 1883, 1884, 1885 ; Schroeder *et al.*, 1938). Investigating the effect of shallow planting, Emerson (1903) found that potatoes planted 1 inch deep yielded 13 per cent more than those planted 4 inches deep. He points out that a further advantage of shallow planting is that when the straw is raked off at harvest time very little digging is necessary. After further experiments he concludes that, although small seed pieces will penetrate the mulch better if they are planted shallow, the best results are obtained by using large seed and planting 2-3 inches deep (Emerson, 1907). Pieper *et al.* (1930) compromise by recommending that the ridges should be levelled as soon as the potatoes are through, to bring the tubers nearer the surface, and the straw applied after that.

Concerning distance of planting, it has been stated that closer planting is possible under a straw mulch as cultivation is not needed and moisture conditions are improved (Emerson, 1903, 1907). A spacing of 18-24 × 12-18 inches gave good results. As both Emerson and later workers (notably Bushnell and Weaver, 1930) have shown, however, that it is wiser to delay straw mulching at least until time of emergence, thus combining spring cultivation with summer mulching, the distance of planting must be sufficient to allow for cultivation in the early stages of growth.

Economics

When assessing the economic value of mulching, the cost of mulch material and the labour of its application and removal are the main items that have to be weighed against a possible increase in yield and quality and a saving in the labour of cultivation. As potatoes are a standard, low-value crop, increased returns are not likely to justify any practice that greatly increases the cost of production.

Little detailed work has been done on the economics of straw mulching for potatoes, but observations made by a number of workers indicate that the labour saved in cultivation is largely balanced by the labour of application and removal of the straw (Bushnell and Weaver, 1930 ; Erwin and Rudnick, 1922 ; Werner, 1933). This means that the price of straw is the critical factor. Even where good results have been obtained from straw mulching it is considered that the practice will only be economic if straw is available cheaply or as a waste product (Bushnell and Weaver, 1930 ; Emerson, 1907, 1914). Certain exceptional circumstances are worth mentioning. In Colombia, although the cost of production under a hay and fern mulch was considerably higher than the cost of cultivation, yields and quality were improved to such an extent

that the total profit was overwhelmingly in favour of mulching (Ernesto Arango, 1948). In Israel, where irrigation water is scarce, the amount of irrigation water required was reduced to almost half by straw mulching, and it could have been reduced even further if the straw had been applied earlier (Amir, 1948). In the central and southern states of America, where vigorous seed stock cannot be produced by normal cultivation methods, it is claimed that seed can be produced satisfactorily and more cheaply under a straw mulch than it can be imported from the north (Emerson, 1914).

In general the choice of mulch material for commercial use will depend on availability and cost. For instance, although manure mulching gave good results in Yugoslavia it is not recommended for commercial use because of its scarcity (Drezgić, 1953), and Wega mulch, which increased yields of potatoes slightly, is considered too expensive (Reinhold, 1942). The same applies to paper mulch. In this case not only is the paper itself expensive but the cost of laying it is very high. Experiments have repeatedly led to the conclusion that with a standard crop like potatoes the use of paper is not economically justified (Boischot and Albert, 1931 ; Canada, Div. Hort., 1930b ; Straight, 1938 ; Woods, 1937 ; and others). Paper, moreover, has the additional disadvantage that until a paper-laying machine is developed which can apply paper over ridged soil it cannot be laid mechanically where potatoes are planted by machine (Maksimova, 1935).

Conclusions

From a survey of the literature on the mulching of potatoes a few general principles emerge.

Straw mulching is likely to prove beneficial in districts where summer temperatures are above the optimum for tuber development and where summer droughts are common. In cool or wet climates it is likely to retard growth and reduce yields. On poorly drained soils it will increase the danger of waterlogging. If applied too early in the season, before the soil is warm, it may retard nitrification and early growth with possible detrimental effects on yield. It will increase the danger of damage by spring or autumn frosts.

Paper mulching is likely to prove beneficial on humus soils with a high water table in districts where summer droughts occur. It may hasten maturity but cannot be relied upon to do so. It will increase the danger of frost damage.

The fact that potatoes have responded favourably to both straw and paper mulching in hot climates suggests that more uniform soil temperatures may be the operative factor, rather than reduced temperatures under straw or possible higher temperatures under paper.

Straw mulching is of special value in the production of seed

potatoes in hot climates ; by retarding the spread of virus diseases it makes possible the maintenance of vigorous stock. It can also be used to reduce incidence of *Colletotrichum* wilt on infected land.

Straw mulching tends to increase the starch and ascorbic acid contents and improve the cooking quality of potatoes, but results have not been quite consistent.

The more constant water supply generally found under any type of mulch will reduce or eliminate secondary growth.

The striking effect of a reed mulch in stimulating the growth of potatoes on strongly saline soil suggests far-reaching possibilities for the use of mulching to restore the fertility of such soils.

Choice of mulching material in commercial practice depends primarily on availability and costs. With this low value crop the use of any material that is not a waste product locally is likely to prove uneconomic. The cost of paper mulching, in particular, is prohibitive.

CHAPTER 10

ROOT CROPS

Beetroot

So little critical work has been done on the mulching of beet with loose organic materials that it is not possible to generalize on its value. In an early straw mulching trial in Nebraska Emerson (1903) included beet among the test crops on various soils. The average yield of beet over a period of three years was little affected by mulching although the strawed crop was a little better in appearance. On low-lying soils in a wet season, however, clean cultivation gave better results than mulching because the covered soil became too wet. Emerson observes that the crop is an easy one to mulch and considers that the practice may be worth while because of the labour saved in cultivation. From a single later trial in Nebraska, however, Werner (1933) concludes that the straw mulching of beet is of doubtful value. In the cooler summers of Montana strawing improved the yield and quality of late beet but did not give good results with the early crop, presumably because the lower soil temperatures retarded growth too much (Montana, 1915). In Israel, where it is generally considered impossible to sow root crops in late summer because the heat is too intense and insect attack is severe, mulching with straw or compost resulted in excellent crops of July-sown beet and, provided the mulch was applied immediately after sowing, germination was good and even as a result of the cooler, moister soil (Borovsky, 1947). In Malaya a trial was made on the residual effect of grass mulch, used on cabbage, on the following crop of beet (Smith, 1955). The treatments applied to the cabbage were (1) grass mulch 4 inches deep, (2) green grass incorporated in the soil, (3) compost dressing at 26 tons per acre, (4) control. The following beet crop gave higher yields on all the treated plots than on the controls, and mulching proved a cheaper method of improving yields than compost dressing.

A preliminary trial on sawdust mulching as a moisture-conserving measure was recently carried out at Saanichton, B.C., an area with very low summer rainfall (Woods, 1951). The soil was a heavy clay loam ; no additional N was given to the mulched plots and no irrigation was used. The first sowing was made directly into a 2-inch layer of sawdust and all the small-seeded crops, including beet, failed to emerge evenly owing to the rapid drying out of the sawdust. A second sowing was made by raking back the sawdust along the drills, sowing the seed on the soil surface and replacing 1 inch of sawdust. Excellent germination was obtained by this

method. During the early part of the season growth was more vigorous on the sawdust plots, but by the end of August nitrate deficiency symptoms appeared and it was found that the soil nitrate level had been considerably depressed by the decomposition of the sawdust. The use of extra N fertilizer to offset such depression is recommended. The yield data, however, showed a distinct trend towards increased yields of beet in favour of mulching, and the benefit appeared to be due very largely to the higher soil moisture content under the sawdust. In Queensland, on the other hand, beet was found to respond very unfavourably to sawdust mulching, the risk of fungus infection being appreciably increased (Summerville, 1955). Two types of sawdust were compared, pine and hardwood, both being applied to a depth of 3 inches. The mulched beetroot succumbed to secondary infection by wood-rotting fungi (*Basidiomycetes*). Although the species were mainly saprophytic ones they apparently became parasitic under conditions favourable for mass infection and the beetroot mortality was high, particularly in the plots treated with hardwood sawdust. The pine sawdust had less deleterious effects but neither type is recommended. In a trial in Connecticut with frame-grown beet the use of a mulch of oak-hickory chips had practically no effect on yield although field moisture capacity was increased (Lunt, 1955).

At the end of the last century Wollny (1897-98), working in Germany, compared the effects of black and white soil coverings (coal grit and granulated marble) on the growth of a number of crops. In each of four seasons beetroot made better growth and produced higher yields under the black cover which absorbed more heat than the white. It is pointed out, however, that the plants would only respond to the greater warmth when soil moisture was adequate. When paper mulch came to be tested on beet more recently it was often found that the heat-absorbing properties of the black asphalt paper also had a favourable effect on yields. The first trials, made in Virginia, were highly promising (Flint, 1928). On a heavy clay soil yields were four times as high on the paper mulched plots as on the controls, and on a loamy soil they were more than doubled. In a very dry season in British Columbia, too, paper mulching more than doubled the yield of beet (Summerland, B.C., 1930). The results of other trials have been less spectacular but quite frequently paper mulching has resulted in higher total yields, a larger early crop pulled for bunching, or earlier maturity (Agassiz, B.C., 1931 ; Florida, 1930 ; Fredericton, N.B., 1930 ; Hill, 1955 ; Hutchins, 1933 ; La Ferme, Quebec, 1931 ; Magruder, 1929a, 1930, 1931b ; Morden, Man., 1930 ; Reinhold and Schmidt, 1930a ; Woods, 1937). Early crop beet has responded better than the main crop (Magruder, 1929a, 1930 ; Morden, Man., 1930, 1938). Presumably this is because the higher soil temperatures under paper are of more value early in the season. With beet, however, as with most other crops, paper mulching has sometimes resulted in failure.

In the hot climate of the Leningrad district, for instance, beet grew badly under black paper (Musso, 1932), and in a German trial the mulched plants were scorched (Tacke, 1928). Reductions in yield or lack of significant response are reported from several sources (Agassiz, B.C., 1930 ; Boresch, 1932 ; Canada, Div. Hort., 1930b, 1931 ; Edmond, 1929 ; Kapuskasing, Ont., 1930 ; Thompson and Platenius, 1932). These failures are not explained but may have been due either to excessive heat or to dry, light soils which are unsuitable for paper mulching.

White paper, which tends to provide cooler conditions by reflecting the sun's heat, has been consistent only in giving results opposite to those obtained with black paper. In Ohio, for instance, where black paper increased beet yields considerably, white paper reduced them (Magruder, 1929a, 1930). In Russia and Germany where conditions on the asphalt papered plots were too hot for satisfactory growth, white paper was beneficial (Musso, 1932 ; Tacke, 1928). On the tropical soils of Hawaii growth of red beet and other temperate vegetables has been greatly improved by the use of white mulch paper (Sherman *et al.*, 1953). Not only were the cooler soil conditions and better water supply under the mulch favourable to growth in themselves, but they also produced a condition favourable to the hydration of manganese oxides in the soil and thus prevented the occurrence of Mn toxicity.

Aluminium foil mulch, which also reflects the sun's rays, prevents fluctuations of soil temperature and reduces evaporation, had an extremely good effect on beet yields and quality in a 3-year trial in Virginia (Wall, 1950). Yields of foil-mulched crops were increased by 70, 110 and 132 per cent respectively in the three consecutive seasons, compared with the controls. At first harvest the ratio of No. 1 beets from the mulched and cultivated plots was 8 to 1 in favour of mulch. It is considered that the larger number of first grade beets under the foil indicates that these roots grew relatively faster than those on the cultivated plots. It seems that in this case the better water supply, the conservation of fertilizers, and/or the stronger radiation of light on the mulched plots must have been responsible for the benefit.

Carrots

This is not a crop that is normally mulched or that one would expect to respond very greatly to the practice, but trials have shown that under certain environmental conditions, particularly adverse ones, mulching may have a marked beneficial effect.

A notable example of this benefit under adverse conditions was provided by a trial with summer-sown carrots in Israel (Borovsky, 1947). As mentioned under **Beetroot**, July-sown root crops usually suffer severely there from the intense heat and insect attack. On the control plots the seed germinated badly, the stand was poor

and the plants unhealthy. On the plots mulched with straw or compost immediately after sowing germination was excellent, less irrigation was needed and the crop was healthier. Delaying mulching until after germination was less satisfactory. It is stated that for a seedbed mulch only a thin layer, 1 cm. deep, should be used, as a deeper layer would tend to cause etiolation and damping off of the seedlings. Aharonovitch and Ulman (1947) obtained similar good results from mulching trials with summer-sown carrots in various districts of Israel, using compost and hay. In three out of four places yields were considerably increased (37-72 per cent) by mulching with either material immediately after sowing. Mulching after germination again resulted in very much smaller yield increases. No explanation is given for the lack of benefit shown at the fourth place.

Pre-germination mulching of root crops is also practised in Nyasaland during the dry season to conserve the moisture supplied by irrigation (Hoyle, 1955). Here, however, it is standard practice and no experimental work has been done. Dry grass is laid about 2 inches thick over the whole seedbed immediately after sowing, and as soon as the seedlings emerge the mulch is lifted slightly to one side to allow unobstructed growth. Other crops are not mulched until they are 2-3 inches high, so it is presumably the slow emergence of the root crops that necessitates pre-germination mulching under hot, dry conditions.

A serious problem associated with seedbed mulching in tropical countries is that the mulch appears to attract termites (Hayter, 1955). Hayter reports that in Southern Rhodesia seedbeds are usually mulched with dry veld grass to ensure even germination, but that the mulch often becomes infested by termites which feed on the grass and coat it with soil particles. As a result the seed becomes covered too deeply with soil. Moreover the termites often eat the seed, especially that of carrots and parsnips. With older seedlings and transplants this encouragement of termites may be beneficial as they work in the soil below the mulch and improve aeration and penetration of moisture.

An interesting little experiment is reported by Aharonovitch and Ulman (1947) on the effect of mulching on health and quality of carrots. They found that mildew attack was reduced by 40 per cent and 60 per cent as a result of mulching with hay and compost respectively. The compost mulch also increased the amount of sugar in the roots from 3·3 per cent in the controls of 3·9 per cent, although the hay mulch reduced it to 3·2 per cent. The difference between the effects of the two types of mulch on the sugar content makes it unlikely that there is any relationship between this factor and mildew resistance, and it is of course not possible to draw any definite conclusions from this single experiment.

Other reports on the straw or hay mulching of carrots are brief and less informative. In Nebraska carrots, unlike other root

crops, responded favourably to a 4-inch cover of straw even on low ground in a wet season (Emerson, 1903). In Montana strawing improved yield and quality of the late crop only (Montana, 1915). And on a sandy loam soil in Germany a 10 cm. mulch of hay was of no benefit (Geisenheim, 1954).

There is only slight evidence to support the theory, mentioned in a popular American journal (W., 1944), that mulching will tend to deter second generation carrot fly. A report from British Columbia (British Columbia, 1946) cites the case of a grower who had no loss from rust fly in a year when he mulched his carrots, whereas in the previous year when no mulch was used the crop had been ruined by the fly. It is suggested that the mulch might have prevented the fly from depositing her eggs on the surface of the soil. Unfortunately no unmulched plots were left as controls in the same year, and the type of mulch material used is not stated. There is room for critical work on this point.

Peat mulch, used in one trial in the Moscow region, had a very favourable effect on the carrot crop, increasing yields from 24 tons per ha. to 55 (Andreev, 1952). The benefit is attributed to the higher soil moisture and nitrate contents and the more even soil temperature under the peat. It is emphasized, however, that for the mulch to be effective it must be applied when the soil is already wet, and the peat itself must have a moisture content of not less than 40 per cent or it will absorb too much water. Annual weeds were largely suppressed by the mulch but perennial weeds penetrated the peat easily.

Results of trials on the use of sawdust mulch provide further evidence that carrots will give the best response under adverse environmental conditions such as insect attack or drought. Fodder carrots grown for five years under a 2-3 cm. layer of sawdust in relatively cool, wet conditions at the University of Vecauce, Latvia (56° 30′ latitude N), generally yielded less than those grown without mulch, and N deficiency was serious on the sawdust plots (Apsits, 1931). In years when *Trioza viridula* attack was severe, however, sawdust reduced the amount of sucker damage considerably, with the result that yields were higher on the mulched plots than on the controls. Paper mulch gave an even greater and more consistent reduction of *Trioza* damage than sawdust.

At the Dominion Experimental Station, Saanichton, B.C., summer drought is a serious problem, and here sawdust mulch, correctly used, proved very successful in increasing yields (Canada, Dep. Agric., 1952 ; Webster, 1954 ; Webster and Adamson, 1955 ; Webster *et al.*, 1952, 1953, 1954 ; Woods, 1951). The trials at this station were started in 1950 with a view to determining the best method of using sawdust for the conservation of moisture. They were carried out with Nantes carrots, among other crops, on a clay loam soil without irrigation. Four treatments were compared : (A) Permanent sawdust mulch with sawdust added yearly to

maintain a depth of 2 inches. (B) No mulch ; 1 inch sawdust incorporated in the soil each spring. (C) No mulch ; a single 4-inch application of sawdust incorporated in the first year only. (D) No mulch ; barnyard manure applied each spring at 10 tons p.a. (control). Additional N fertilizer was added to the sawdust plots to offset the depressive effects of the decomposing sawdust. The marketable yields of early carrots obtained from the four treatments [see also Fig. 5] are summarized in the following table :

Treatment	Yield in lbs per acre			
	1951	1952	1953	Average
A. 2 in. sawdust mulch ..	16,655	16,399	8,050	13,701
B. 1 in. sawdust incorporated annually ..	1,281	12,043	17,552	10,292
C. 4 in. sawdust initially incorporated	5,723	18,790	14,904	13,139
D. Barnyard manure ..	940	6,235	4,313	3,829

It can be seen that the yield was much higher from the three sawdust-treated plots than from the manured plots, the conservation of soil moisture by the sawdust being the main reason for the heavier crops. The sawdust mulch and the 4 inches of sawdust incorporated gave approximately the same average yield over the whole period, although it is of interest that in the first year the yield was considerably higher from the mulched plots. The reason for this decreasing benefit from mulch is important. Sawdust mulch is more effective in conserving moisture, especially in the top 2 inches of soil, than sawdust incorporated, and this fact probably accounts for the higher initial yields. It was found, however, that clay soils become very compact under sawdust mulch after the first year, resulting in lower marketability of roots, whereas soil in which sawdust has been incorporated remains open and friable. In the first year a higher percentage of the total crop was marketable on the mulched than on the other plots, but in subsequent years marketability was lower under mulch. The roots were shorter and thicker than those on the sawdust incorporated plots, and much rougher and more constricted owing to the compaction of the soil. On soil made friable by the incorporation of sawdust, on the other hand, the roots were long and smooth. [See Fig. 5.] In order to overcome this disadvantage of mulching on clay soils, it is suggested in the Saanichton reports that the first year's mulch should be incorporated with the soil at the beginning of the second year [see Fig. 4], additional nitrogen added, and further sawdust applied as a mulch. This practice should give good moisture conservation combined with open soil texture. No further sawdust should be incorporated for at least four years.

A further point that emerges from these experiments concerns

the germination of carrot seed under sawdust mulch. Seed sown in the spring directly into a 2-inch mulch failed to germinate evenly because the sawdust dried out too rapidly. For satisfactory germination it was found necessary to rake the sawdust back along the drill, sow on the soil surface and replace 1 inch of sawdust. July-sown carrots failed to germinate in all treatments, except in one year under the mulch, owing to the dry soil conditions, and it is concluded that at Saanichton irrigation must be used in conjunction with sawdust where summer sowings are made.

Even at Agassiz, B.C., where summer drought is less serious than at Saanichton, sawdust mulching improved carrot yields in in each of two years (Agassiz, B.C., 1954). An alternative method of sowing suggested in a circular from Agassiz (Fletcher *et al.*, 1952) is to sow the seed on the soil surface before mulching, to scatter a thin layer of sawdust over it and to increase the depth of the mulch as the crop grows.

As regards weed control by sawdust, a 2-inch mulch will give good control of most annuals, excepting chickweed, but will not suppress persistent perennials such as Canada thistle and creeping yellow cress ; couch grass, however, tends to be shallow-rooted under sawdust and is relatively easily pulled (Fletcher *et al.*, 1952 ; Webster *et al.*, 1954 ; Woods, 1956).

Paper mulching has generally been less successful on carrots, a cool season crop, than on the heat-loving crops, but a certain amount of benefit has been obtained as a result of moisture conservation, more even temperatures, weed control or pest control. In the trials in Latvia (Apsits, 1931), for instance, considerable yield increases were obtained from " rubéroide-thermogène " paper mulch owing to almost complete control of *Trioza viridula* ; in one year when 95-100 per cent of the uncovered carrots were attacked by the sucker, the damage on the paper covered plots was reduced to 0-2 per cent. Better germination and/or earlier maturity, allowing a larger crop of early carrots pulled for bunching, has sometimes been reported as a result of paper mulching (Florida, 1930 ; Fredericton, N.B., 1930 ; Hill, 1955 ; Hutchins, 1933 ; La Ferme, Quebec, 1931 ; Magruder, 1930 ; Standen, 1930 ; Woods, 1937). It seems likely that this more rapid early development was due to improved moisture conditions and more uniform temperatures under the paper. Increased yields due to paper mulching have been reported from six other trials (Flint, 1928 ; Magruder, 1931b ; Morden, Man., 1930, 1938 ; Reinhold and Schmidt, 1930a ; Schomerus, 1931), whereas no significant yield differences were observed in four trials (Canada, Div. Hort., 1931 ; Edmond, 1929 ; Kapuskasing, Ont., 1930 ; Summerland, B.C., 1930).

In tropical countries where high soil temperatures are a serious limiting factor in the cultivation of temperate vegetables, white paper mulches which reflect radiant heat are more likely to be beneficial than black ones. In Hawaii, for instance, the growth

of carrots has been greatly improved by the use of white mulch paper (Sherman *et al.*, 1953). Moreover, on a highly manganiferous soil in Hawaii a mulch of board slats, which reduced soil temperature and increased moisture, decreased the amount of exchangeable Mn in the soil to about one-fifth of that present in the bare soil (Sherman and Fujimoto, 1947). This was due to the fact that hydrated Mn oxides are less soluble than the dehydrated oxides, and the mulch prevented dehydration. The growth of carrots was found to be closely related to the ratio of exchangeable Mn to exchangeable Fe in the soil, and as a result of the reduction in exchangeable Mn yields of carrots were increased almost 4-fold by the use of a board slat mulch. The application of hydrated lime in conjunction with slat mulching increased yields still further. This is another example of mulch being used successfully to counteract extremely unfavourable growing conditions.

Even in temperate countries, however, light-reflecting mulches have sometimes given fairly good, though less striking results with carrots. In Germany white paper increased yields by 54 per cent (Tacke, 1928), and in Ohio by 25 per cent (Magruder, 1930). At the Virginia Truck Experiment Station the use of aluminium foil mulch resulted in an 84 per cent increase by weight in crop yield, and yield of grade 1 carrots from the mulched plots was 1·84 times as great as that from the cultivated plots (Wall, 1950). In Florida also carrots on foil-mulched plots were significantly earlier and larger than the controls, and it is considered that the benefit was probably due to the conservation of moisture, the reduction of soil temperatures, less leaching of soluble fertilizers and control of weeds (Burgis, 1951 ; Florida, 1949-50).

An uncommon method of mulching, with a film of bituminous emulsion sprayed over the soil surface, has attracted considerable interest in Russia. Like asphalt mulch paper, the bitumen absorbs heat and increases soil temperatures by an average of about 2° C. It has the advantage over mulch paper that it can be applied over the whole soil surface including the seed row or over broadcast seed, but for this very reason it is ineffective in controlling weeds. In the Far North of Russia carrot yields were almost doubled by the use of this film as a result of the higher soil temperature (Banasevič, 1941). A covering of soot, similarly applied as an emulsion in water, also had a favourable effect on carrot yields, though the increase was smaller than with the bituminous emulsion.

Celeriac

The edible portion of celeriac consists of the swollen upper part of the root and base of the stem which together form a tuber. One essential for the cultivation of this crop is a good supply of moisture to prevent deep rooting. In dry soils thick deep roots tend to develop and small tubers result. By conserving moisture

in the upper layer of soil, therefore, mulching will be likely to improve yield and quality of tubers. It must be remembered, however, that mulches are not always effective in conserving moisture ; very light, permeable soils over a deep water table, for instance, may become drier when they are covered with paper mulch as rain water will penetrate less easily, and a peat or sawdust mulch, if it is too dry, may absorb light showers before they have penetrated to the underlying soil. But in all the tests on celeriac reported in the literature mulching has proved beneficial.

Field trials on straw mulching were carried out at the Karl-Marx University of Leipzig on a sandy loam soil poor in humus (Bielka and Hildebrandt, 1954). Treated plots were covered with 3 cm. straw at planting time. A high June rainfall provided a good initial supply of moisture but the rest of the summer was dry, thus allowing the moisture-conserving action of the mulch to come into play. Where the mulched plots were given the same complete fertilizer treatment as the controls strawing increased yields by 25·5 per cent and improved quality. Even where no fertilizer was applied to the mulched plots they yielded practically as much as the fertilized control plots and the tubers were still of better quality. It is suggested that the improved conditions of moisture and aeration and the more uniform temperature under straw had not only a direct effect on tuber formation but also an indirect effect by increasing the activity of soil organisms. An examination of the soil fauna in the upper 7 cm. of these plots showed that the populations of collembola, centipedes, etc., and particularly of earthworms, were much higher under the straw. The authors point out that the more abundant soil life would increase CO_2 production in the soil and thus favour carbohydrate synthesis.

Trials with peat mulch also gave good results at Wolbeck in Germany (Badke, 1939, quoted Bayer, 1951). It was found that a thin layer of peat greatly improved the texture of the soil and increased yields of eight varieties of celeriac by 34-83 per cent, the average increase being 57 per cent. In Czechoslovakia an alkaline peat refuse from sugar factories (peat + slaked lime in a 10:1 ratio) was used for early celeriac in frames, either as a mulch 5 cm. deep or mixed with the soil (Zlatkovský, 1952). In both cases the yield of tubers was increased (13 per cent by the mulch), and the use of alkaline peat combined with sowing *in situ* is recommended as the most satisfactory method of forcing celeriac.

Celeriac is the one crop that has responded consistently well to Wega mulch, a fibrous black woodwool. Schomerus (1930, 1931) claims that its use will prevent the development of deep thick roots and encourage fibrous root production even in a dry summer. He considers that it is an almost ideal mulching material in that it decomposes less rapidly than other organic materials, lasting 3-5 years, and absorbs heat, but that unlike paper mulch it is permeable and can be walked on. He reports that even in a wet

season, when Wega mulching had little effect on the yield of other crops, celeriac responded very favourably and produced larger tubers under the mulch (Schomerus, 1931). A few years later Wega mulch was tested on a larger number of crops at various stations in Germany over a period of two years (Reinhold, 1942). In general the material did not fulfil its early promise. Although it reduced temperature fluctuation, the soil under Wega was usually found to be cooler than bare soil. Most crops showed little or no benefit, but celeriac on peaty soil showed an average yield increase of 8·6 per cent as a result of mulching and the flavour of the tubers was improved. The increase is admittedly small but it is larger than that obtained with any of the other crops. The benefit is attributed to the fact that celeriac is a plant with a low heat requirement and was grown on a soil with high specific heat.

In one of the first large scale trials with asphalt mulch paper, carried out at 25 research stations in Germany, outstandingly good results were obtained with celeriac (Otto, 1926). The yield increase averaged about 120 per cent, and the mulched soil had a better structure, better moisture supply and higher bacterial activity. Yield increases of from 10 to 116 per cent as a result of paper mulching are also reported from Germany, Czechoslovakia and America (Böhnert, 1926 ; Boresch, 1932 ; Hutchins, 1933 ; Reinhold and Schmidt, 1930a and b, 1933 ; Schomerus, 1931) ; in some cases paper mulching also resulted in larger, better quality tubers or earlier maturity. Reinhold and Schmidt (1930a) make an interesting observation in connection with their paper mulch trials : they noticed that the young celeriac plants on the control plots were very badly damaged by hares, whereas those on the mulched plots remained untouched. They suggest that the hares must either have been afraid to walk on the paper or have been deterred by its smell.

Parsnips

That parsnips will respond to the better moisture supply under mulch during a drought season has been shown by a test with asphalt paper mulch in Ohio, when a yield increase of 147 per cent was obtained (Magruder, 1931b). In a normal season in Minnesota paper mulching gave only a very small increase of 9·5 per cent (Hutchins, 1933). Parsnips, however, appear to respond particularly unfavourably to excessive soil moisture. In a very rainy year on lowland soil in Nebraska, parsnips did better on cultivated soil than under straw mulch, although the reverse was true for carrots ; the quality of the strawed parsnips was poorer, many roots being fibrous and spongy (Emerson, 1903).

Radish

Mulching experiments with radish are mainly of interest for the general principles that emerge. Musso (1932), working in the

Leningrad region, compared the effects of straw mulch, black paper, waxed paper and no mulch on the growth of white radish. The moisture content of the soil, a humus loam, was little influenced by the various treatments, so the effects were mainly temperature ones. In general the soil under straw was cooler and that under black paper warmer than bare soil. Under waxed paper the soil warmed up slowly in the morning but lost its heat only very gradually. The temperature differences between soil and air were as follows : under straw, large by day, small by night ; under black paper, small by day, large by night ; under waxed paper, large by day and night ; bare soil, medium by day and night. Musso contends that a large temperature difference between soil and air by day will promote root formation. This is borne out by the fact that under straw the radish roots developed more quickly and the leaves more slowly than on the controls, whereas under black paper the reverse was true. The only treatment which resulted in an increased yield of roots, however, was waxed paper mulch which created a large temperature difference all the time. Soil temperatures also had a marked effect on the shape of the leaves ; with straw mulch the leaves were round, with black paper they were elongated and serrated, on the controls they were intermediate, whereas with waxed paper they were large and broad. These leaf differences were only noticeable in the young plants, and did not persist after the roots had penetrated to a depth at which soil temperatures were unaffected by mulching.

Another experiment of a fundamental type was carried out at Grossbeeren to determine the response of radish to mulching under different soil conditions (Reinhold and Schmidt, 1930a). Here the emphasis was on moisture, not temperature. Containers were filled with either moorland (peaty) or mineral (sandy) soil and watered to capacity. Some were then mulched with asphalt paper and others left uncovered as controls. Some of the containers were kept at full water capacity, others were kept at 60 per cent (peat) or 25 per cent (sand) of full water capacity, while a third set was given no further water at all. Radish showed by far the greatest response to mulching when water was withheld. By preventing evaporation the paper was able to maintain sufficient moisture in the soil to meet the needs of this rapidly maturing crop. Yield increases due to mulching on the unwatered soil were 241 per cent for peat and 112·5 per cent sand. Mulching also increased yield significantly (by 57·7 per cent) on the sandy soil kept at 25 per cent water capacity, but not on that kept at full water capacity. On the peat soil kept at 60 per cent and full water capacity there were only yield increases of 1·1 and 22·2 per cent respectively as a result of mulching. Thus with a short season crop such as radish mulching is most likely to be effective when a dry period follows the early spring rains. It is interesting that the results of these trials do not accord with Musso's findings that black paper mulch was detrimental

to root production. Even where moisture supply was not a limiting factor, yields were not actually reduced by the mulch.

In the few field trials recorded on the mulching of radish it is difficult to determine which is the dominant factor involved. In two consecutive seasons in Minnesota an asphalt paper mulch hastened germination and early growth of radish and increased yields by 33 per cent (Hutchins, 1933). In Ohio also paper mulch resulted in stronger growth and reduced the amount of root maggot damage, but in this case no yield data are given (Magruder, 1930). In Czechoslovakia a yield increase of about 30 per cent is recorded for black winter radish in favour of paper mulching (Boresch, 1932). Even in cold frame culture it has been used successfully, giving a 44 per cent yield increase (Reinhold and Schmidt, 1930a). At Saanichton, B.C., radish was more productive under a sawdust mulch than in bare soil, owing to the better moisture supply [see Fig. 6], but maturity was retarded by the cooler conditions under the sawdust (Woods, 1951). It is noteworthy that radish was the only small-seeded crop used in these trials that emerged fairly well when sown directly into the 2-inch layer of sawdust. This was because the seed germinated quickly, before the sawdust had dried out.

Swedes

Although this crop has probably too low a value to justify the expense of mulching, it has sometimes benefited from the practice. In a trial in Saskatchewan during an exceptionally dry season mulching with a 6-inch layer of strawy manure increased swede yields by 20 per cent, and mulching with black paper by 31 per cent (Indian Head, Sask., 1931). A paper mulch trial in Ohio also gave favourable results even though the dry weather in this case did not start until the middle of August (Magruder, 1930). Here black paper increased yields by 43 per cent and white paper by 119 per cent, indicating that a mulch which reduces soil temperature is preferable. In Minnesota, however, swedes responded very unfavourably to black paper mulch in a normal season, and gave only a small yield increase in the following drier season; germination was retarded by the mulch in both years (Hutchins, 1933).

The only sawdust mulch trial reported on swedes (Woods, 1951) is perhaps an unfair one because no additional nitrogen was applied to the mulched plots to offset the N depression caused by decomposition of the sawdust. It was carried out at Saanichton, B.C., where summer rainfall is very low. During the early part of the season growth was much more vigorous on the sawdust plots than on the controls owing to the better moisture supply. By early August, however, nitrate deficiency appeared in the mulched plants with the result that final yields were reduced. Being a late-maturing crop swedes suffered more from this nitrate depression than the short season crops.

Turnips

As in the case of swedes mulching is unlikely to be economic with turnips and is rarely practised. Where straw is available and cheap it should prove a suitable summer mulch for turnips. The only experimental work available on strawing comes from Montana (Montana, 1917), and even in this northern state turnips benefited slightly from the lower soil temperature under straw. Sawdust mulch would also help to keep the soil cool, but here again work on turnips has been negligible. Information is limited to the observation made at Chertsey that cabbage root fly attack was more severe on turnips under a sawdust mulch than on those in cultivated soil (Chase, 1952).

Paper mulching has generally proved very unsuccessful with turnips, although in the first trial in Virginia the average weight per plant of summer turnips was increased 212 per cent by asphalt paper (Flint, 1928). In Minnesota turnips, like swedes, responded unfavourably in a normal year and showed only a slight increase in a drier year ; germination was retarded by the mulch (Hutchins, 1933). The Ohio trials resulted in decreased yields of late turnips, unlike swedes, with both black and white paper (Magruder, 1929a, 1930). It is suggested that the lower yields were probably due to the higher temperatures under the mulch, since soil moisture, which is the limiting factor in the production of late crop turnips, was increased by the mulch ; this may have been true in the case of black paper but does not explain the effect of white paper which tends to keep the soil cooler.

Conclusions

Although root crops have often responded favourably to mulching, they will not generally have a sufficiently high market value to justify the use of expensive mulch materials. Results have shown, however, that the practice is at least worth consideration as a moisture-conserving measure where mulch material can be obtained cheaply and the cost of application is covered by the saving in cultivation. Moreover, under particularly unfavourable environmental conditions mulching may well make the difference between success and failure.

In districts where drought makes it difficult to succeed with summer sowings of root crops, pre-germination mulching with a thin layer of straw, hay or compost has improved emergence of carrots and beet and resulted in larger, healthier crops. Such a mulch will also have the advantage of reducing the amount of irrigation water needed and may reduce the amount of mildew infection.

On tropical soils, where dehydration of manganese oxides tends to produce manganese toxicity, mulching with light-coloured paper or board slats has improved yields of carrots and beet by keeping

the soil cooler and moister and thus decreasing the amount of exchangeable manganese.

Sawdust mulching is likely to increase yields of root crops in dry seasons provided it is used correctly. It is important, however, (1) to add sufficient nitrogen fertilizer to offset depletion by decomposition of the sawdust, (2) to sow the seed directly on the soil surface and cover lightly, and (3) to prevent compaction of clay soils under sawdust. There is evidence that sawdust mulch may help to reduce damage by *Trioza viridula* but it may increase cabbage root fly attack. It has also been found that secondary infection of beet by wood-rotting fungi may become a serious problem, especially where hardwood sawdust is used.

Among the root crops, celeriac has responded outstandingly well to mulching, since it requires a good supply of soil moisture to prevent deep rooting and to encourage tuber formation.

CHAPTER 11

SWEET PEPPERS AND EGGPLANTS

General

The sweet pepper, *Capsicum annuum*, and the eggplant, *Solanum melongena*, are related both botanically and in their climatic requirements. The former is probably a native of tropical America and the latter of S.W. Asia, so both require a warm, frost-free climate. The pepper is the more temperate of the two. In a careful study of the growth of peppers under controlled conditions Dorland and Went (1947) found that flowering and fruitset were most abundant at night temperatures of 15·5-20·5° C. (60-69° F.) for young plants, but for older plants the optimum night temperature was only 8·5° C. (47° F.). In Hawaii it is even classed as a cool weather crop; if grown at temperatures above 65-75° F. fruitset is usually poor, and sunburning and blossom end rot of the fruits may become serious (Nakagawa, 1951). The eggplant seems to enjoy tropical conditions. Both require an ample and well-distributed supply of moisture, the eggplant being the less tolerant of drought (Beattie and Doolittle, 1937).

Considering the high moisture requirements of these crops, and the fact that they are grown in warm regions where irrigation is generally necessary, it is surprising that the advisory circulars and general articles on their culture rarely mention the possibility of mulching. And this is even more surprising in view of the fact that mulching trials have in the large majority of cases given very favourable results, particularly with the eggplant. In the many paper mulching trials that have been carried out in the United States and Canada it was generally the heat-loving crops such as cucurbits, tomatoes, eggplants and peppers that responded best. Moreover these are fairly high value crops that might justify the expensive treatment. In very hot districts such as Natal, Missouri and Nebraska the cheaper straw and hay mulches have also proved very beneficial. It is therefore quite conceivable that in places such as Hawaii, where pepper yields are low during the very hot summer months, bulky organic mulches might be used to great advantage not only to conserve moisture but also to maintain a more favourable soil temperature.

Effects of Mulching

On yield

Few experiments have been carried out with loose organic mulches, and these chiefly in hot climates where a reduction in soil

temperature could readily be tolerated by these heat-loving crops. In Missouri, where lack of moisture at some time during the summer is a limiting factor to vegetable growing, the effect of straw mulching was studied over a period of four years (Rosa, 1923). A 4-6 inch layer of wheat straw was applied early in the season while the soil was still moist. The mulch increased yields of eggplants substantially every year, the average increase being 50 per cent. Peppers showed less benefit, the average increase being only 10·9 per cent. The benefit is attributed to reduced soil temperatures and less fluctuation of soil moisture content. The better response shown by the eggplants may be related to their greater need for a regular supply of moisture. In a straw mulch trial in Nebraska excellent results were obtained with peppers (up to 61 per cent increase) in each of three years (Werner, 1933). Eggplants also responded favourably (up to 94 per cent increase) in each of four years, with the exception of the irrigated crop in a season of well distributed rainfall when presumably the controls had sufficient moisture. In interpreting these results it is of interest to compare those of paper mulch trials carried out at the same time and place. Although peppers generally gave a yield increase in favour of paper mulching, compared with unmulched plots, the yields were always lower than those obtained with straw mulching. This suggests that peppers benefited from the cooler soil conditions under the straw as well as from the higher soil moisture under both types of mulch. Eggplants also responded well to paper mulching in all but one case, and under dryland conditions paper gave slightly higher yields than straw ; on the irrigated plots, however, straw was slightly preferable. These differences were small, but the results as a whole indicate that in a hot climate moisture conservation is the most important effect of mulching, and that the soil-cooling properties of straw are likely to be of more value to peppers than to eggplants.

A report from a more temperate region (New Jersey, 1896, 1897) is concerned mainly with the effects of hay mulching on the incidence of disease, so the results will be discussed more fully under *Pests and diseases*. It is of interest to note, however, that in a dry year small yield increases were obtained with both crops as a result of mulching after the plants were well established. As favourable results were also obtained from irrigation, the better moisture supply was probably responsible. Indeed, in the following year, with abundant rainfall, hay and excelsior mulches had no appreciable effect on yield. It would be unwise, therefore, to assume that loose organic mulches could safely be used in cooler regions.

Wega mulch, a bitumen-impregnated woodwool, is also a loose organic mulch but it is black in colour and thus tends to absorb heat. Opinions on its soil warming capacity have varied, but a careful study (Reinhold and Schmidt, 1933) revealed that it acted primarily as an insulator : although soil temperature under Wega was lower on the average than that of bare soil, sudden drops or extremes of

temperature were avoided. Bayer (1951) mentions that in Austrian trials substantial yield increases were obtained from the use of Wega on peppers and eggplants. Unfortunately no details are given.

Another temperature-reducing mulch, aluminium foil, has recently been tested on a large number of vegetables, including peppers, in the warm climate of Virginia (Wall, 1950). The foil has excellent light-reflecting properties and affords good conservation of moisture and nutrients. Yields of peppers were one-third larger on the mulched plots than on the controls. It is doubtful whether this type of mulch could be used successfully on heat-loving crops in cooler regions, although it is possible that the increased radiation might partly compensate for the lower soil temperature.

The effect of paper mulching on peppers and eggplants was studied in some detail by workers in Virginia over a period of three years (Westover and McCubbin, 1934). On heavy soil peppers gave a higher number and weight of fruit for both the early and total crop under paper, but on very light soil only the early yield increase was significant and the value of mulch was considered questionable. With eggplants paper mulching on heavy soil resulted in significant yield increases in relatively dry seasons, whereas on light soil it again made little difference to the crop. These results are accounted for by the fact that the paper was found to increase soil moisture to a much greater extent on heavy than on light soil. The conclusion that paper mulching is more profitable on heavy soils is in accordance with the findings of almost all other serious investigators and is of general application to most crops. With heat-loving crops, however, it is probable that in relatively cool regions the greater warmth provided by the paper may be of benefit even on light soils where moisture conditions are not greatly improved. This would explain some of the apparent exceptions to the above generalization that appear in a survey of results of paper mulch trials with peppers. For instance, yield increases were obtained on sandy loam soils in Canada (Canada, Div. Hort., 1930b, 1931), Michigan (Edmond, 1929) and New York (Thompson and Platenius, 1932), where temperatures would probably be below the optimum for pepper production. On heavier soils favourable results were obtained in the majority of trials (Boresch, 1932 ; Flint, 1928 ; Hutchins, 1933 ; Lerch, 1930 ; Magruder, 1928, 1930 ; Werner, 1933), but the few unexplained cases of failure (Hutchins, 1933 ; Kaserer, 1927 ; Magruder, 1931a ; Werner, 1933) go to show that the effects of paper mulching are still not fully understood. It can only be said that this heat-loving crop is likely to respond better than the more temperate vegetables. With eggplants the prospects are even more promising. With the exception of the Virginia trials on very light soil mentioned above, eggplants have almost invariably responded favourably to paper mulching, yield increases of over 100 per cent being not uncommon (Agassiz, B.C., 1930, 1931, 1937 ; Boresch, 1932 ;

Canada, Div. Hort., 1936 ; Flint, 1928 ; Fredericton, N.B., 1930 ; Magruder, 1928, 1930 ; Morden, Man., 1930 ; Rhode Island, 1930 ; Standen, 1930 ; Summerland, B.C., 1930, 1931 ; Werner, 1933 ; Woods, 1937). All these trials were carried out on medium or heavy soil. The exceptional case of reduction in yield obtained on silt loam in Minnesota (Hutchins, 1933) remains unexplained.

On growth and maturity

Recent tests in Arizona (Anon., 1954) have shown that emergence of many vegetables can be improved by the use of a $\frac{1}{2}$-inch deep mulch of vermiculite over the seed rows. It prevents soil crusting, holds moisture and is a good insulating material. Peppers were not used in these trials but it is reported that growers have obtained excellent results with vermiculite mulch on this crop.

The retarding effect of straw, hay, etc., on vegetative growth has been observed for many crops, especially in a cool season or when the mulch is applied before the soil has warmed up. On excessively hot soils, however, this protection of the soil against baking sun and leaching rain may be essential for normal growth. This was the case in Natal (Wager, 1944) on humus-deficient red sand which tended to become extremely hot and dry in spite of copious rainfall. Here eggplants given a grass mulch when they were a few inches high grew to 3-4 times the size of unmulched plants within a month or so.

As part of an extensive series of trials on straw and paper mulching of vegetables in Nebraska (Werner, 1933), a study was made of the root systems of eggplants, tomatoes and sweet potatoes under both types of mulch. This valuable piece of fundamental work goes far to explain the yield responses of these crops, for it was found that yields were more definitely in proportion to size and development of the root systems than to leaf and stem development. If similar work were carried out in several different soils and climates some of the mysteries still surrounding mulching responses might be solved. This study was made on fertile, heavy silt loam with a high water-holding capacity but tending to puddle when wet and crack when dry ; the season was very hot and dry. Werner found that in cultivated soil the root system of the eggplant had a very limited development, with few main roots and few feeding roots and a downward habit of growth. Under straw both main and feeding roots were more numerous and profuse ; they were concentrated mostly in the top foot of soil and made lateral growth, many feeding roots coming to the surface. Under paper the growth was more extensive both downwards and laterally ; the roots were attracted to the surface just beyond the edge of the paper where moisture entered the soil. Apart from the obvious advantage of a greater number of feeding roots, their lateral extension under mulch enabled them better to utilize the more fertile upper layers of soil.

With regard to top growth Werner notes that the paper mulched

plants made more vigorous early growth than the controls although they were usually smaller at the end of the season. On the other hand, straw mulching before the plants were set reduced early development, the mulched plants remaining smaller than the controls throughout the season and being lighter green in colour, especially during cold or rainy periods. Higher yields, however, were almost invariably obtained. Hence the conclusion that yields are more closely related to root growth than to top growth.

Although this conclusion seems justified, it does not necessarily mean that top growth is no indication of the benefit of mulching. It is likely that in many cases top growth will reflect root growth fairly accurately. Westover and McCubbin (1934), for instance, found that the analysis of the growth data of paper mulched plants on different soils closely coincided with the yield results. On heavy soils, where both peppers and eggplants gave yield increases as a result of mulching, the mulched plants grew faster and remained larger throughout the season, the difference invariably being easily discernible to the eye, whereas on light soil, where yield responses were not significant, no growth difference was evident from casual inspection and none of the measurement data showed significant differences. There are several other reports of increased vigour associated with increased yield as a result of paper mulching (Bassi, 1930 ; Boresch, 1932 ; Canada, Div. Hort., 1930b, 1931 ; Hilton and Giffen, 1950 ; Magruder, 1930 ; Morden, Man., 1930). In a 2-year trial in Minnesota, however, early growth was stimulated by paper but the difference was not maintained, while total yields of eggplants were lower in both years, and of peppers in one year, than in the controls (Hutchins, 1931, 1933). In Ottawa, where the season is generally neither warm enough nor long enough to ensure a good crop of eggplants, paper mulching improved growth but did not make it possible to produce a marketable crop (Canada, Div. Hort., 1930b). In Florida growth of peppers was actually reduced by paper mulching, no explanation being given (Florida, 1930).

As might be expected, cropping has been retarded by straw mulching (Rosa, 1923) and generally hastened, in one case by as much as 28 days, by paper (Bassi, 1930 ; Canada, Div. Hort., 1930b ; Hilton and Giffen, 1950 ; Hutchins, 1933 ; Lerch, 1930 ; Magruder, 1930, 1931a ; Morden, Man., 1930 ; Standen, 1930 ; Werner, 1933 ; Westover and McCubbin, 1934 ; Woods, 1937). In one trial in Ohio paper-mulched eggplants produced about six times as much early fruit as the cultivated plants, while mulching had no effect on the earliness of peppers, although total yields were increased in both cases (Magruder, 1928). Aluminium foil, which reduces soil temperatures during warm days and increases them on cool nights, caused earlier fruiting of peppers in Virginia (Wall, 1950). The reasons for this are not clear but it may be due to the better moisture and nutrient supply which kept the plants growing rapidly.

On quality

There is little specific information on the quality of mulched peppers and eggplants. Woodwool (Wega) mulch, used in Austria, is reported to have improved yields and quality of both crops (Bayer, 1951). In a drought season in New Jersey peppers were somewhat larger and of better quality as a result of hay mulching (New Jersey, 1897). In a comparison of straw and paper mulching, Werner (1933) notes that the quality of all the vegetables tested, including peppers and eggplants, was better on the straw plots. The data presented by Westover and McCubbin (1934) in their paper mulch study show that the yields of marketable No. 1 fruits were closely related to total yields. On heavy soil mulching increased both total yields and weight of No. 1 fruit of peppers significantly every year, while with eggplants the increases for both total yields and No. 1 fruit were significant only in the relatively dry years. On very light soils there were no significant differences for either total yields or No. 1 fruit with peppers, while with eggplants weight of No. 1 fruit was significantly decreased in years when total yields were slightly reduced. Although this indicates that a larger quantity of better fruit may be obtained under conditions favourable to paper mulching, it was also found that paper mulching tends to increase the amount of rotted, cracked and sunscalded fruit. On heavy soil the weight of rotted fruit (mostly blossom end) was always higher, sometimes significantly so, on the mulched plots with both peppers and eggplants. It is suggested that this was due to the greater vigour of the mulched plants early in the season when rainfall was plentiful. On light sandy soil, where mulching did not significantly affect vigour or total yields, there was also a tendency for the mulched plants to produce more fruits with blossom end rot. The authors admit that the reason for this is not apparent unless it was due to the extremely dry conditions during the latter part of the season. Eggplants on the sandy soil also produced more sunscalded and cracked fruit on the mulched plots ; this is attributed to the higher temperatures combined with shortage of rainfall.

On pests and diseases

In the Florida experiments to determine the value of vegetable mulches for control of root-knot eelworm (Florida, 1938-1951 ; Watson, 1943, 1944) eggplants were among the many test plants used. No specific information is given on the responses of this crop, but the investigations as a whole showed that mulches were not effective in controlling the nematode, although they did improve growth and yields on nematode-infested soil.

An interesting piece of work was carried out by Halsted in New Jersey (New Jersey, 1896, 1897) showing that hay mulches may tend to reduce anthracnose infection of peppers and leaf spot of eggplants. The experiment with peppers was designed to determine the value of bordeaux sprays for control of anthracnose

(*Colletotrichum nigrum*). Some of the sprayed plots were mulched with old hay two months after planting. In a dry season the percentage of diseased fruits was as follows : control 8·0, bordeaux alone 12·48, bordeaux+mulch 6·16. On the sprayed plots the percentage of sound fruits was increased by 12·95 in favour of mulch, the gain being partly due to increased yields and partly to a slight reduction in disease. In the following year, however, with abundant rainfall, mulching had no effect either on yields or prevalence of disease. With eggplants bordeaux was applied against leaf spot (*Phyllosticta hortorum*), some of the plots being mulched with fresh hay after the plants were well established. In the dry season the percentage of diseased fruit was : control 65, bordeaux alone 52, bordeaux + mulch 25. The mulched plots gave the highest yield and the lowest number of diseased fruits, the increase in sound fruit on the sprayed plots being 66·66 per cent in favour of mulch. Again mulch gave no benefit the following wet year. No reason is suggested to account for the reduced amount of infection under dry conditions. Whether it was due to a reduction of dew formation and consequently of spore production, or to the increased vigour of the plants is a matter for speculation. Further investigation along these lines might prove profitable.

It has been suggested that mulching in hot climates may reduce wilting, caused partly by mechanical damage from the soil and partly by fungus infection through the wounds. Megalov (1940) reports that wilting of peppers and eggplants in certain areas of Southern Russia is attributed to *Fusarium* or *Verticillium* infection. He considers, however, that the fungi are only secondary factors, the primary cause being high temperatures at the soil surface which cause coagulation of the protoplasm and death of the cells at the collar where the tissue comes into direct contact with the hot surface layer of soil. Fungus infection follows through the damaged area and intensifies wilting. He also suggests that mechanical injury, allowing fungal infection, may be caused by the hard crust that is formed when the soil dries out in hot sun following rain or irrigation. Protection of the soil by mulching is one of the measures recommended to prevent such wilting.

Economics

In hot climates straw mulching has been recommended as a satisfactory substitute for irrigation. In Missouri, although not quite so effective as irrigation, it was considered cheaper, more labour-saving and more convenient on a small acreage (Rosa, 1923). In Nebraska it proved just about as effective as irrigation on eggplants, though less so on peppers (Werner, 1933).

In cooler districts paper mulching has given fairly consistent benefits, but whether it will prove economic will depend on the price of the paper. In the most recent trials in British Columbia eggplants, cucumbers and melons were the only crops that gave large

enough responses in yield and earliness to offset the price of the paper and the extra expense of handling (Woods, 1937). In New York, where paper is cheaper, its use on peppers was considered profitable, largely owing to increased earlier yields (Thompson and Platenius, 1932).

Conclusions

Straw mulching has proved of considerable value on eggplants and peppers in hot climates as a moisture conserving measure. Peppers may benefit from the cooler soil conditions under straw. On extremely hot soils it may prevent wilting due to injury of the collar tissues and subsequent fungal infection. In cooler climates straw cannot be recommended for these heat-loving crops.

Eggplants and peppers are among the crops that have benefited most from paper mulching. It has given very consistent increases in yield and earliness with eggplants, and fairly consistent increases with peppers. It is more likely to be profitable on heavy, moisture-retaining soils than on sandy soils, especially in warm districts. Paper tends to increase the amount of blossom end rot and, on light soils, of sunscalded and cracked fruit. Where yields are increased, however, the percentage of good quality fruit is also generally increased. The economic value of this practice will depend on the price of the paper.

CHAPTER 12

TOMATOES

FIELD TOMATOES

General

Field tomatoes can be a profitable crop, given sufficient warmth, moisture and care. For this reason mulching is often considered a justifiable expense and it is widely practised commercially in many parts of the world. The main purpose for which it is used is as a moisture-conserving measure in dry summers or on well-drained soils. By improving moisture conditions it will tend to increase yields and reduce the amount of blossom end rot. Moreover where tomatoes are grown unstaked a mulch will help to keep the fruit clean and reduce fruit rots. In the warm states of America large areas of tomatoes are sometimes grown under mulch ; straw or marsh hay are the materials generally used, and special precautions have to be taken to prevent nitrogen deficiency (Edmond, *et al.*, 1951 ; Nissley, 1945 ; Shoemaker, 1947 ; Weaver and Bruner, 1927). In Israel straw is used by growers to reduce the amount of irrigation water needed (Borovsky, 1947), and in Kenya where tomatoes are often grown unstaked grass mulching is common (Jackson, 1954). English authorities recommend the use of a light cover of straw to prevent the soil from drying out, to protect the surface roots and to provide clean conditions beneath the crop (Bewley, 1950 ; N.A.A.S., 1950). Loads (1952) suggests the use of peat or " almost any organic substance which will not stick together when wet ".

Many materials have been tried experimentally on outdoor tomatoes, including asphalt paper, aluminium foil, bagasse, glass, corn fodder, compost, manure, sawdust, peat, pine needles, woodwool, polyethylene and papier mâché. None of these, however, has yet become firmly established in commercial practice. It is convenient at this point to describe briefly the work that is being done with papier mâché mulch (Hamner and Rai, 1954, 1955), as the trials have so far been only preliminary and no detailed results or crop figures appear to have been published. With a view to finding an efficient, economic method of weed control, trials were started at the Michigan State College on the use of a mulch of paper pulp made by soaking old newspapers in water and agitating them by mechanical means until the paper is shredded. The pulp is then spread round the plants and the water contained in it either evaporates or soaks into the soil, leaving a hard, cardboard-like mulch which suppresses weed growth and conserves moisture.

Tomato growth on mulched plots is said to have been good. The outstanding advantages of this method are its cheapness and the ready availability of waste newspaper. As a more practical development of the earlier expensive system of paper mulching it appears worthy of attention.

Seedbed Mulching

In very many parts of the world where tomatoes are raised in open field seedbeds, some form of mulch is needed over the beds to prevent the soil from drying out and to give protection from sun or cold during germination. In the southern U.S.A. disinfected burlap or canvas used to be the materials generally used (Beattie, 1924 ; Weber and Kelbert, 1940). More recently black building paper has been recommended as this also provides extra heat (Porte, 1952). The covers, of course, have to be removed as soon as the first seedlings appear.

In Rhodesia it is recommended that open seedbeds should be mulched with a thin layer of dry grass, which is removed when the seedlings emerge (Marshall, 1945). In the Lowveld of South Africa seedbeds on heavy soil are frequently covered with a thin layer of sifted compost or rotted manure through which the seedlings grow. Workers at Nelspruit Research Station, however, consider that it is preferable to use a grass or muslin cloth cover when it is necessary to protect the beds from severe spells of heat or cold (van Blommestein and Malan, 1954). They recommend that the cover should not be laid on the ground as a mulch, but should be raised about 2 feet above the surface of the soil and only removed when the danger of frost is over. In Jamaica, where a heavy layer of grass or bush is used, it is recommended that as soon as the seedlings appear the mulch should be lifted and set on sticks about 1 foot above the beds ; it can then be thinned out gradually to prevent the seedlings being burnt by sudden exposure to the sun (Anon., 1930).

In Queensland shade is sometimes necessary to obtain even germination, and the Fruit Branch of the Department of Agriculture, Qd (1950) suggests that straw or even bags should be laid on the ground after sowing and removed as soon as the seedlings begin to appear. A thin layer of cut straw, 1 cm. deep, has also been recommended as a seedbed cover in Israel, but here it is sometimes the practice to leave the mulch on after germination and to add more straw a few weeks later ; if a thick layer were used at first it might cause etiolation of the seedlings and favour damping-off diseases (Borovsky, 1947). Here it was found that tomatoes failed to germinate when bedding straw from poultry houses was used as a mulch, and it is suggested that this material may be too rich in nutrients. In the Jordan Valley a sawdust mulch not only improved seedling growth but also had a markedly repellent effect

on white fly (*Bemisia tabaci*) which seriously attacked the unmulched seedlings (Avidov, 1956).

Effects of Mulching

On yield

Mulches of straw, hay or other loose organic materials are generally considered to be very effective as a means of conserving moisture, and therefore to be very beneficial to field tomatoes in hot, dry districts or during drought. As they tend to reduce soil temperatures, however, there is the danger that in colder climates they may make conditions too cool for satisfactory growth. Moreover such mulches may deplete soil nitrogen so much during decomposition that yields are adversely affected. Even when the material itself is not rapidly decomposed by bacteria, the cooler soil conditions and reduced aeration may tend to retard nitrification processes in the soil. It is mainly the interaction of these factors that determines the success of mulching with plant residues.

In the United States the best results have been obtained in the warmer central or southern states. In Pennsylvania in 1931 tomatoes mulched with straw produced 21·4 tons of ripe fruit per acre compared with 15·1 tons for the unmulched crop, and similar results are said to have been obtained in Missouri (Edmond *et al.*, 1951). Corn fodder mulch, to a depth of 2-3 inches, also gave highly beneficial results in a test at Pennsylvania State College, the mean increase in yield being 26 per cent (Isenberg and Odland, 1950). In this case application of additional N made no significant difference to yields. These authors also compared the performance of tomatoes grown under five different mulch materials, with and without N, namely sawdust, oak leaves, corn fodder, grass clippings and manure. There was no significant difference in yield as between any of the materials, and again no response was obtained from the N treatment. These results indicate that any convenient waste organic material can be used for mulching, and that N deficiency need not be expected provided the soil has been well manured and is of high fertility. Delaying mulching until the plants had been cultivated once or twice resulted in higher yields than applying the mulch immediately after planting [see **Time of Mulching**].

Emerson (1903) in Nebraska also found that straw mulching was generally beneficial to tomatoes, but that strawing before the plants are well established would retard early growth and reduce yields. Later extensive trials in Nebraska (Werner, 1933) showed that in almost every case strawing increased tomato yields. The mulch, however, which was applied before planting, did reduce early growth. The soil was well manured and fertile, and additional N was not consistently beneficial. In Missouri, where shortage of soil moisture is generally a limiting factor to growth in summer, a straw mulch gave an average yield increase of 13·5 per cent over

a period of four years ; only in one wet season did it prove harmful (Rosa, 1923). In a very dry year in Ohio substantial increases were obtained from mulching with grass clippings, although the average results over a 3-year period showed little difference in yields between the mulched and control plots (Ohio, 1922).

In Hawaii where high soil temperatures tend to induce manganese toxicity, mulching has been especially beneficial (Gilbert, 1956). A 1½-inch layer of composted sugar cane bagasse covered by 1½ inches of fresh bagasse increased yields of tomatoes by an average of 4 tons per acre. The purpose of the double layer was to combine the fertility improvement of the composted material with the weed control and heat deflecting properties of the fresh bagasse.

Even though mulching has thus been shown to be beneficial in many cases under warm, dry conditions, other reports clearly indicate the danger of mulching on poor soils. On such soils N deficiency induced by mulching may more than offset the advantages of improved moisture conditions. In a long-term experiment in Ohio, in which fresh straw was applied annually at 7 tons per acre to soil of low fertility, tomato yields were reduced on the average by 14 per cent ; the plants had a yellowish appearance indicating N shortage (Gourley and Magruder, 1924). Hoffman (1929b) also cites a case of reduction in yield of field tomatoes following a mulch of fresh strawy manure at 16 tons per acre, and attributes the trouble to depletion of N. Slightly lower yields were also obtained in Ohio as a result of mulching with alfalfa-timothy hay, but no explanation is given for this result (Wittmeyer, 1947).

In the more northerly states of America mulching with plant residues seems less likely to be beneficial, even on fertile soils, as the temperature under mulch may become too cool for satisfactory growth. In Montana, for instance, tomatoes did better under normal cultivation than under a straw mulch ; the temperature under the straw was sometimes as much as 10° cooler, and in that climate a sufficiently high soil temperature was found to be as important for growth as an adequate supply of moisture (Montana, 1915). In New Jersey, where the climate is warmer than in Montana but more temperate than in the hot, dry states of Ohio or Nebraska, results have been variable and appear to depend largely on the season. In two years with severe summer droughts, for instance, tomato yields were increased by mulching with old hay or salt hay, whereas in a season with abundant rainfall the crop was unaffected by mulches of fresh hay, salt hay or excelsior woodwool (New Jersey, 1896, 1897, 1899). In a later trial in New Jersey, five mulch materials (salt hay, wheat straw, clover hay, bagasse and green hay) were tested on three varieties of tomato (Tiedjens, quoted Isenberg and Odland, 1950). In a wet season, although mulching was beneficial in most cases, the control plots outyielded those mulched with salt hay and wheat straw in the case of the Rutgers variety. In a dry year mulching was beneficial in every case.

The same trends can be traced in the results of trials carried out in other countries, with the exception that N deficiency appears to be a less serious problem, or at least to have attracted less attention. In Israel, where summers are hot and water is very scarce, straw mulches are said to result in better growth and cropping and to reduce the amount of irrigation water needed (Borovsky, 1947). In one place a mulch of straw + cottonseed waste increased yields of tomatoes by 75 per cent and reduced the amount of water needed from 480 m^3 per dunam to 320 (Griss, 1949). At the Government Experiment Station at Acre, hay and compost mulches both gave yield increases of about 17 per cent (Aharonovitch and Ulman, 1947). At Seyda in Prussia it is reported that good results have been obtained over a period of several years from the use of a pine needle mulch on tomatoes grown on poor sandy soil (Murawski, 1931). At Geisenheim in Germany a 10 cm. mulch of hay and a 15 cm. mulch of straw increased tomato yields by 15 and 29 per cent respectively, and prevented deterioration of the sandy loam caused by sprinkler irrigation (Geisenheim, 1954, 1955). In a trial at Leipzig (Bielka and Hildebrant, 1954) on poor sandy loam a 3 cm. mulch of straw increased yields by 47 per cent when the same manurial treatment was given as in the controls, and by as much as 73 per cent when the fertilizer was all applied as a base dressing instead of in two split applications. Even the unmanured mulched plots cropped as heavily as the manured controls. The benefit is attributed to the better conditions of soil moisture and aeration and the more uniform soil temperature, which together favoured microactivity in the soil.

In certain important lumbering regions, where sawdust is a plentiful waste product, this material has recently been widely tested as a mulch or soil improver for horticultural crops. Like other organic materials it conserves moisture, reduces soil temperatures during warm periods, and may produce N deficiency if it becomes mixed with soil and starts to decompose. Tests in Alabama (Johnson, 1944) showed that old pine sawdust could be applied as a mulch to tomatoes without harmful effect if sufficient N was added. In these tests a 3-inch mulch was applied and left on for three years, two rates of N fertilizer being given. Nitrates were only slightly depressed in the first year, but there was an increasingly greater depression during succeeding years as the sawdust became gradually mixed with the soil. Tomato yields were increased by mulching in the first year, especially where additional N was given, but there was little difference due to treatment in the second year. By the time the mulch had become incorporated with the soil in the third year, yields were again favourably affected. In a circular from the Experimental Farm, Agassiz, B.C., sawdust mulches are not recommended for warm season crops such as tomatoes (Fletcher *et al.*, 1952). Work at Saanichton, B.C., however, where rainfall from April to September inclusive averages only 6·6 inches, has shown

that unirrigated tomatoes may respond very favourably to such treatment. Results of a preliminary trial there with 2-inch sawdust mulch showed a distinct trend towards increased yields, although maturity was retarded (Woods, 1951). In a long-term trial a continuous sawdust mulch, with sufficient sawdust added yearly to maintain a 2-inch depth, was compared with the following three treatments without mulch : 1 inch sawdust incorporated in the soil each spring, 4 inches sawdust incorporated in the first year only, and barnyard manure applied at 10 tons per acre ; additional N was given to all the sawdust plots (Webster *et al.*, 1952, 1953, 1954. See Fig. 7). In the first year of test the 4-inch incorporated treatment gave the highest yield (7·4 lb. per plant), followed by the sawdust mulch (6·2 lb.), both being markedly better than the other two treatments (1·7 lb. for 1-inch incorporated, and 1·4 lb. for barnyard manure). In the second year the same two treatments were again the best, but the mulched plots slightly outyielded the 4-inch incorporated plots. In the third year the 1-inch annual incorporation treatment and the sawdust mulch gave the best results ; the difference between these treatments was not significant. Thus sawdust mulching proved one of the most satisfactory treatments and in all cases gave distinctly better results than the incorporation of barnyard manure. Averaging the results for the whole 3-year period, the mulched plots produced the highest yields. The higher yields are attributed mainly to the conservation of moisture. The importance is stressed, however, of providing sufficient N to offset any deficiency which may occur during decomposition of the sawdust, and the use of 60 lb. extra N per acre in addition to the crop requirement is recommended. At the Cawthron Institute in New Zealand, where a 2-inch sawdust mulch was ploughed into the soil in the spring and more sawdust added as a top dressing, the need for additional N was clearly demonstrated (Cawthron Institute, 1951-55). Even with high rates of N, the harmful effects of mixing the sawdust with the soil were apparent. In the first year of test, before any sawdust had been ploughed in, yields on the mulched plots were lower than those on the controls with a single dose of N, higher with a double dose and considerably higher with a treble dose : the crop figures on the sawdust plots were 4·5, 6·7 and 7·4 lbs. per plant for the single, double and treble N rates respectively, compared with 5·4, 5·6 and 5·7 lbs. on the controls. The higher soil moisture content under mulch in dry weather appeared to be beneficial, although in wet weather the mulched soil became very wet and the plants reacted unfavourably. The following year the adverse effects of ploughing in the old mulch showed up, particularly on the plots receiving the single rate of N. Only in the case of the treble dose was there a slight increase in yield in favour of mulch. Similarly in the third year the detrimental effects of previous applications of sawdust on growth, yield and quality were marked. In the fourth year, however, when no

further sawdust was added, the mulched plots produced higher yields and better quality fruit than the control plots at corresponding levels of N. Good results with sawdust have also been reported by growers in New Zealand (Matthews, 1948) and Hawaii (Swanson, 1953).

Peat is another material that has sometimes been tested experimentally as a mulch for tomatoes, although in America it is considered too expensive for commercial use (U.S.D.A. Office of Information, 1945). In a trial at Berlin-Dahlem it was found to increase yields of tomatoes by 31 per cent (Höstermann, 1927) and the author suggests, though without experimental evidence, that this was due to the improved conditions of warmth, moisture and aeration in the soil. Reinhold and Schmidt (1933), however, working at the same place, investigated more closely the physical effects of a peat mulch and showed that although it did improve the moisture content of the soil it generally reduced the temperature, especially during warm periods, and decreased aeration. In their experiments yields of tomatoes grown on sandy soil were reduced 12 per cent by a peat mulch. On a moorland soil near Moscow, on the other hand, a dry peat mulch had a favourable effect on tomatoes, a yield increase of 70 per cent being obtained (Ložkin, 1935). It appears that the conditions under which peat can be used successfully are not yet fully understood.

Very variable results have also been obtained with woodwool, another fibrous organic material. One type of woodwool, known as excelsior, was tested in New Jersey over 50 years ago (New Jersey, 1897), but the season was warm and wet so the benefits of mulching were not apparent and tomato yields were unaffected. Later a proprietary type of woodwool, impregnated and black in colour, was brought onto the market in Germany under the name of Drawin or Wega mulch. Its insulating properties prevented evaporation and stabilized soil temperatures. It was thought that the black colour would have a heat absorbing effect but evidence on this point is conflicting. In one of the earliest trials with this material in Germany, tomato yields were unaffected, but the season was a very wet one which made moisture conservation unnecessary (Schomerus, 1931). Trials carried out with Wega mulch in Vienna (Bayer, 1951 ; Kopetz, 1935a and b) showed that minimum temperatures were always higher under the mulch and that maximum temperatures were lower until mid-August but higher in the late summer ; it was therefore thought that the mulch should be suitable for plants not requiring high spring temperatures but benefiting from warm autumn conditions. The soil remained moister and had a better crumb structure under the cover and weeds were suppressed. In four successive seasons tomato yields were increased by 38, 111, 27 and 8 per cent, the small increase in the last case being due to the very wet season. Trials in Germany by Reinhold and Schmidt (1933), however, proved that, although

Wega mulch increased the water content of fen soils, it did not do so on sandy soils, and that on the latter tomato yields were unaffected by mulching. Moreover in these trials Wega mulch did not suppress weeds satisfactorily and cultivation through the mulch was extremely difficult and expensive. Summarizing the results of seven trials in different parts of Germany, Reinhold (1942) states that tomato yields were decreased by an average of 14 per cent by Wega mulch, weed control was unsatisfactory and the material was too expensive for commercial use.

Reinhold and Schmidt (1933) also tested the value of coke dust from brown coal as a mulch material on a number of crops. Although this suppressed weeds satisfactorily it generally proved harmful to the crops and reduced tomato yields by 24 per cent.

The use of mulch paper impregnated with asphalt, which attracted so much attention in the years between the wars, has been widely advocated for field tomatoes. It was thought that this valuable, heat-loving crop would benefit sufficiently from the warmer, moister conditions under paper to justify the high cost of material and labour for mulching. In the innumerable experiments that have been carried out in America, Canada, Europe and Russia results have often, though by no means always, been favourable, but opinions concerning the economic value of the practice have varied widely. It would take too long to describe here all the experimental results in detail (Agassiz, B.C., 1930, 1931 ; Anon., 1926, 1927 ; Bassi, 1930 ; Böhnert, 1926 ; Boischot, 1930 ; Boresch, 1932 ; Canada, Dep. Agric., 1930 ; Canada, Div. Hort., 1928, 1930a and b, 1931, 1936 ; Diev, 1935 ; Eckart, 1923 ; Edmond, 1929 ; Flint, 1928 ; Fredericton, N.B., 1930 ; Gleie, 1926 ; Graefe, quoted Reinhold and Schmidt, 1930a ; Hatt, 1926 ; Heine, 1930 ; Höstermann, 1926, 1927 ; Hutchins, 1933 ; Jensen, 1926 ; Kapuskasing, Ont., 1930 ; Kaserer, 1927 ; Kentville, N.S., 1929 ; Kuznecov, 1935 ; La Ferme, Quebec, 1931 ; Langer, 1927 ; Lerch, 1930 ; McCubbin and Westover, 1933 ; Magruder, 1928, 1929, 1930, 1931a and b ; Mann, 1931 ; Marchi, 1929 ; Moen, 1926 ; Morden, Man., 1930, 1938 ; Moulton, quoted Schomerus, 1931 ; Mutzek, 1926 ; Otto, 1926 ; R—, 1929 ; Reinhold and Schmidt, 1930a and b, 1933 ; Rhode Island, 1930 ; Robb, 1929 ; Rubin, 1935 ; Schomerus, 1927, 1931 ; Standen, 1930 ; Summerland, B.C., 1930, 1931 ; Thompson and Platenius, 1932 ; Torstensson, 1931 ; Vogel, 1929 ; Weihenstephan, 1929 ; Werner, 1933 ; Woods, 1937 ; v. Wrangell, 1927, 1929b). Some of the more important fundamental work, however, may help to throw light on the conditions under which paper mulching may be expected to increase yields. In order to investigate the influence of soil types on the results of paper mulching tomato crops, experiments were carried out by McCubbin and Westover (1933) in Virginia on a silty clay loam and a fine sandy loam over two seasons. On the clay soil mulching resulted in significantly greater growth and higher yields in both

years ; the soil moisture content was increased and the average soil temperature was higher. On the sandy soil, however, there was no significant difference in growth or yields in one season, and a slight decrease in total yields due to mulching in the other, very dry season; the soil moisture content was not consistently affected and it was thought that the higher temperatures under the paper during the drought period may have been injurious. From these results it is concluded that paper mulching is more likely to be beneficial on medium or heavy soils than on light soil. These findings are in close accordance with results obtained in Germany by Reinhold and Schmidt (1930a). Using a wide range of crops, these workers found that paper mulching was more effective in increasing soil temperatures on humic than on mineral soils and on moist than on dry soils. The soil moisture status under paper mulch was also shown to be improved to a greater extent in soils well supplied with water from below than in very well drained soils in which there is less water to be conserved by the prevention of evaporation. The results of Russian work with paper mulched tomatoes (Kuznecov, 1935) also support this theory, for in 18 trials on clay soil the average yield increase was 36 per cent, whereas in three trials on sandy soil it was only 10 per cent.

Attention has recently been paid to the possibility of using mulches to increase the radiation of light [see also under **Glasshouse Tomatoes,** p. 141]. For field-grown tomatoes aluminium foil has generally been tested for this purpose. Száva-Kováts (1948), working in Hungary, considered that most crops did not require such an accumulation of heat as occurred in normal soils in that climate, and that greater benefit would be obtained by causing part of the heat to be reflected in the form of light, thus reducing soil temperatures and evaporation and increasing the intensity of radiation. To achieve this he covered the soil, in one year, with thick paper coated with lime, and in the next year with aluminium foil painted white. The average albedo of the white paper was 0·85 and that of the foil 0·75, whereas the natural albedo of the soil was only 0·18. The paper mulch was either left on all day and removed at night or left on for part of the day only. In the first case tomato yields were increased by 81 per cent and in the second case by 87 per cent. It is suggested that the better results on the intermittently covered plots were due to the fact that the quantity of solar energy received by the plots covered all day exceeded the optimum value for assimilation. The aluminium foil cover, with lower albedo but left on permanently, resulted in an even greater yield increase of 104·6 per cent. The benefit is attributed partly to the higher moisture content of the covered soil and partly to the greater intensity of radiation which increased the rate of assimilation. It was noticed that the mulched plants produced more flowers, and the suggestion is made that the increase in light intensity may have affected the activity of the flowering

hormone. Unfortunately it is not stated whether the plants were staked or trailing, a factor which would affect the amount of radiation. Weger (1951a and 1952) later investigated the effect of unpainted aluminium foil on bush tomatoes in Germany. The intensity of radiation from the foil was more than three times as strong as from the uncovered soil. In spite of rainy weather which made conditions unsuitable for this experiment, tomato yields were increased by 15 per cent on the mulched plots. Good results with aluminium foil mulch were also obtained at the Virginia Truck Experiment Station, staked tomato yields being increased by 29·5 per cent (Wall, 1950). In the report of this work, however, no mention is made of a direct benefit from increased radiation ; the good results are attributed to its indirect effects, namely lower soil temperatures during the warm part of the day and higher soil moisture, to the warmer conditions at night and to suppression of weeds.

Another material that has been tested as a means of increasing the radiation of light for tomatoes is glass. For this purpose Weger (1953) used Dutch lights placed over the soil between the rows and sloped at a slight angle towards the plants. The effect of this covering on the microclimate round the plants has been described in detail in the section on *Cucurbits*. The amount of light radiated from the glass was considerable, even during dull weather. The main differences between the effects of the glass and aluminium foil as soil covers were the higher soil temperatures and the drier conditions in the upper 10 cm. soil layer under glass. During the first part of the harvest period tomato yields were slightly lower on the glass covered plots than on the uncovered, but they soon caught up and by the end of the season a yield increase of 17 per cent was obtained in favour of glass. Weger mentions in particular two factors which may have been responsible for the higher yields : the protection of the soil from panning and crusting, which resulted in a more open structure and allowed a more extensive root development, and the increased radiation which may have resulted in plants with a greater reproductive capacity.

An exceptionally promising new mulch material that is now being tested at the University of Kentucky is black polyethylene plastic (Emmert, 1956a and b). This is less fragile and costly than either asphalt paper or aluminium foil but has similar soil-warming properties and forces the crop well. In a preliminary trial its use increased early yields of tomatoes by 40 per cent and gave a substantial increase in total yields in spite of a wet season.

On growth and maturity

Although the use of straw and other loose organic mulches may often produce heavier tomato crops, especially in dry seasons, mulched plants usually grow more slowly than clean cultivated ones and remain smaller and lighter green in colour throughout the

season (Emerson, 1903 ; Isenberg and Odland, 1950 ; Shoemaker, 1947 ; Werner, 1933). This retardation of growth appears to be due to the cooler soil conditions, poor aeration and reduced nitrate supply which often occur under mulch. An exception to this response is reported from the coastal belt of Natal (Wager, 1944) where tomato plants mulched with a 4-inch layer of grass grew bigger and stronger than those grown on exposed soil ; in this case the soil was a very poor red sand which became excessively hot and dry unless the surface was protected by a mulch.

In spite of the fact that top growth is generally slower as a result of mulching with plant residues, root growth appears to be stimulated. Isenberg and Odland (1950) suggest that although low soil temperatures early in the season are unfavourable for early growth, by midseason and later they are more favourable for root development. They found, moreover, that the feeding roots of tomato grew extensively in the upper 5-6-inch layer of soil under various organic mulches, whereas in cultivated soil they were mainly down at the 5-6-inch level owing to the drier surface conditions. Thus the mulched plants were able to utilize more fully the nutrients in the fertile upper portion of the soil. Werner (1933) also compared the root systems of cultivated and straw mulched tomatoes and obtained similar results. He found that clean cultivated plants had a limited root development, with few main and few feeding roots, mainly growing downwards ; under a straw mulch both main and feeding roots were more numerous, they made lateral growth and were found mainly in the top foot of soil with many feeding roots coming to the surface. To complete the picture, he describes how under paper mulch the root system was more extensive in all directions than under either straw or cultivation, and many roots were attracted to the surface of the soil just beyond the edge of the paper. A Canadian report (Canada, Div. Hort., 1928) states that the soil below paper mulch was a mass of fine feeder roots. This better root development under mulch is probably largely responsible for the higher yields often obtained.

Tomatoes mulched with straw, sawdust and similar materials are not only slower growing but generally mature later than cultivated plants, owing to the lower soil temperatures. Many workers have reported that smaller yields were obtained during the early part of the harvest season, or that the greatest increase in yield occurred late in the season (Aharonovitch and Ulman, 1947 ; Bielka and Hildebrandt, 1954 ; Isenberg and Odland, 1950 ; New Jersey, 1899 ; Rosa, 1923 ; Webster *et al.*, 1954 ; Wittmeyer, 1947 ; Woods, 1951). In one trial in Israel, however, under very warm conditions, picking started nine days earlier on the plots mulched with straw and cottonseed waste than on the controls, and harvesting continued for a week longer at the end of the season (Griss, 1949). Under the very dry conditions in Saanichton, B.C., sawdust mulching also sometimes resulted in slightly earlier fruit than cultivation

(Webster and Adamson, 1955). It is considered that in this case the effect of soil moisture on earliness was more pronounced than the effect of soil temperature, and that, had moisture conditions been more favourable, then soil temperatures would undoubtedly have played a more dominant role.

The growth response of tomatoes under paper mulch is very different from that under straw. When soil and weather conditions are such that paper will effectively increase soil temperatures and moisture, growth is generally more rapid and the fruit tends to ripen earlier. Stimulation of vegetative growth, especially in the early part of the season, has been observed in many paper mulch trials (Bassi, 1930 ; Canada, Div. Hort., 1930b ; Flint, 1928 ; Kaserer, 1927 ; McCubbin and Westover, 1933 ; Magruder, 1928, 1930, 1931a and b ; de Marcillac, 1930 ; Morden, Man., 1930 ; Mutzek, 1926 ; Weihenstephan, 1929 ; Werner, 1933 ; v. Wrangell, 1929b). On sandy soil, however, where moisture conditions were not improved by paper mulching, vegetative growth of tomatoes was unaffected (Gleie, 1926 ; Heine, 1930 ; McCubbin and Westover, 1933). Earlier flowering is reported by Bassi (1930) and Mutzek (1926).

The warmer conditions under paper mulch have frequently resulted in earlier ripening of fruit ; for instance, in trials in Italy and Germany the first picking was eight days earlier on the papered plots (Bassi, 1930 ; Otto, 1926), in Canada nine days earlier (Standen, 1930) and in Russia 0-12 days earlier (Diev, 1935). Earlier yields or higher yields during the early part of the season have also been obtained in many other experiments (Becker, 1926 ; Canada, Div. Hort., 1931 ; Eckart, 1923 ; Fredericton, N.B., 1930 ; Hatt, 1926 ; La Ferme, Quebec, 1931 ; Schomerus, 1927 ; Summerland, B.C., 1931 ; Thompson and Platenius, 1932 ; Weihenstephan, 1929 ; Werner, 1933 ; v. Wrangell, 1929b). Although there is thus a marked tendency for paper mulching to hasten maturity, it will not do so under all conditions. Hutchins (1933) reports that its effect on earliness varied with both season and variety, and Boresch (1932) found that late varieties responded to paper mulching with earlier yields but that a very early variety with a low heat requirement did not do so. In 12 trials in Germany the effect of paper mulching on soil temperatures, and consequently on time of ripening, varied greatly (Anon., 1926). Heine (1930) reports that harvesting did not begin earlier on covered plots but the fruit ripened more quickly, with the result that less green fruit remained on the plants at the end of the season, whereas Magruder (1928, 1930) found that maturity of pruned tomatoes was actually delayed by paper mulching and more unripe fruit remained at the end of the season. Cases in which maturity has been unaffected by paper mulching are quite common (Boischot, 1930 ; Boischot and Albert, 1931 ; Canada, Div. Hort., 1928 ; Gleie, 1926 ; Höstermann, 1926 ; Langer, 1927 ; Moen, 1926 ; Morden, Man., 1930 ;

Torstensson, 1931), as also are reports of retarded maturity (Canada, Div. Hort., 1930a and b ; Kaserer, 1927 ; Kentville, N.S., 1929 ; Magruder, 1931a and b). It is thus clear that under suitable conditions paper mulching will stimulate growth and hasten maturity, but that unsuitable soil or weather conditions or the use of early varieties may prevent these good effects.

In a preliminary trial with black polyethylene plastic the mulched tomatoes were several weeks ahead of the controls and the early crop was increased by 40 per cent (Emmert, 1956a and b).

Increasing the radiation of light by covering the soil with whitewashed paper or aluminium foil stimulated the growth of tomatoes very considerably in one trial in Czechoslovakia, causing earlier and more profuse blossoming and earlier ripening of the fruit, although the height and foliage development of the plants remained unaffected (Száva-Kováts, 1948). In a German trial, however, unpainted aluminium foil had no effect on earliness, in spite of the fact that it increased the intensity of radiation (Weger, 1951a, 1952). Covering the soil with Dutch lights, another method of increasing radiation, stimulated early growth but did not hasten maturity; in the early stages the plants had thicker stems and more foliage and were slightly taller than the controls, but by the end of the season they were 9 cm. shorter ; less fruit ripened over the glass during the early part of the harvest season, although total yields were finally higher (Weger, 1953).

Another factor that has to be taken into account when comparing the advantages of different mulch materials is the danger of frost damage. Werner (1933) reports that frost occurred later in spring and earlier in autumn and was more severe over a straw mulch than over clean cultivated land. Chase (1952) observed that tomatoes grown under cloches with a sawdust mulch were killed by a late frost in May, whereas those grown with a compost mulch or with clean cultivation were unharmed. Paper mulching on the other hand appears to protect plants to some extent from frost damage. Otto (1926) found that paper mulched tomatoes withstood frost better than the controls, and Standen (1930) quotes the case of an English trial in which paper mulched tomatoes produced a good crop when the unmulched plants were nearly all cut down by frost.

On quality and composition

One self-evident advantage of mulching, particularly in the case of unstaked plants, is that the fruit does not come into contact with the soil and is therefore kept cleaner and the amount of spoiled fruit is reduced (Jackson, 1954 ; Kaserer, 1927 ; New Jersey, 1897 ; Raymond [undated] ; Shoemaker, 1947 ; Talbert and Hibbard, 1943). In the case of black plastic mulch it has even been claimed that ground spotting of unstaked plants is almost eliminated and

that the plastic may be used to replace staking (Emmert, 1956a and b).

In extensive trials in Nebraska Werner (1933) found that strawed tomatoes had fewer small, rotting or rough fruits than clean cultivated plants, but more sunburnt fruits because there was less foliage to give shade. Paper mulched plants also gave a higher percentage of primes than clean cultivated plants where irrigation was used because fewer small or rotten fruits were produced. In 3 out of 5 of the unirrigated tests, however, paper mulching decreased the percentage of primes ; this was due to more rotten and rough fruits in the case of Earlianna and more small fruits in the case of Marglobe. Comparing the effects of straw and paper mulching on quality, Werner concludes that straw mulching always resulted in a higher percentage of primes and fewer rotten fruits than paper, and that the fruits were generally larger ; on the strawed plots sunscald was worse on Earlianna but less on Marglobe than on the paper plots.

Other authors report that the quality of tomato fruits was unaffected by straw (Bielka and Hildebrandt, 1954) and by Wega woodwool (Reinhold, 1942), but that the appearance of fruit mulched with salt hay was far superior to that of unmulched fruit (New Jersey, 1899). Tarfree paper has improved the yield of grade 1 fruit, whereas tarred paper had no effect on quality (Hatt, 1926 ; Weihenstephan, 1929). With aluminium foil there was a 48 per cent. increase in grade 1 fruit (Wall, 1950). In a series of trials in British Columbia sawdust mulching increased the percentage of first grade fruit in two seasons but decreased it in a third (Webster *et al.*, 1952, 1953, 1954). In New Zealand (Cawthron Institute, 1951-55) the quality of sawdust mulched tomatoes was only better in the first year of mulching on plots receiving a treble dose of nitrogen, and in the fourth year when no further sawdust had been added for two years. In these trials, however, the old mulch was incorporated with the soil in the spring of the first year and more sawdust added in the second year, so trouble arose from N deficiency. More hard-core developed on the sawdust mulched plots than on the controls, and although the use of N was effective in reducing the amount of hardcore, larger applications were required to effect an improvement on the sawdust than on the unmulched plots.

The effect of mulches on cracking and splitting of tomato fruits is not clear, although it seems reasonable to suppose that any practice which affects water relations, rate of growth and foliage development would also affect cracking. Recent trials in Ohio to determine the effects of various cultural treatments showed that shading the fruit, either artificially or by encouraging the production of foliage, helped to reduce cracking, but that mulching was ineffective (Brown and Wittmeyer, 1947 ; Wittmeyer, 1947). In fact the material used, alfalfa-timothy hay, increased the percentage

of fruit showing severe cracking from 4·5 in the controls to 6·1. Paper mulching on a light soil in Virginia also tended to increase the amount of cracked fruit, although it made little difference to the soil moisture content or the vegetative growth of the plants (McCubbin and Westover, 1933). Covering the soil with glass, which resulted in greater foliage production, reduced the number of split fruits (Weger, 1953). Mulching with black plastic resulted in little or no cracking and greatly improved the quality of the fruit (Emmert, 1956a and b). More critical work on this point would be useful.

Some interesting work has been done recently on the nutritive value of mulched tomatoes. In a 6-year experiment at the Massachusetts Agricultural Experiment Station (Holmes *et al.*, 1948) tomatoes grown on fine sandy loam were mulched with the following materials : (1) horse manure with wood shavings continuously for six years ; (2) rye straw continuously for six years; (3) banana fibre for three years followed by Servall (shredded sugar cane stalks) for three years. The mulches were applied 4 inches deep each spring after planting and were ploughed in each autumn. The fruit was assayed in the sixth year of the trial only. It was found that mulching made no difference to the water, total solids, total sugars or ascorbic acid contents, but that fruit from the mulched plots contained somewhat more soluble solids and carotene, and definitely more Ca, Mg, P and K. The Servall and straw plots gave the highest values for carotene, Ca, Mg, Mn, P and K, while the Servall plot gave the lowest value for N. The most marked effect was thus an increase in minerals. In another experiment at Budapest the effect of white mulches, which reflect light, was studied (Száva-Kováts, 1948). Mulch paper coated with lime, giving an average albedo of 0·85, was applied during the daytime only. Fruit from the covered plot showed a marked increase in vitamin B_1 content and a slight increase in nicotinic acid, but the dry mass, reducing sugars, vitamin C and acid contents remained unchanged. The following year aluminium foil, painted white and giving an average albedo of 0·75, was used as a permanent soil cover. In this case no significant difference was obtained in any of the above factors. It is surprising that in these two experiments the ascorbic acid content of the fruit was unaffected by any of the mulches used. It is now a generally accepted fact that the ascorbic acid content of tomatoes is greater in unshaded than in shaded fruits, and therefore tends to decrease with an increase in the amount of foliage. One would thus expect vitamin C production to be affected by mulching either indirectly as a result of the effect on foliage production, or directly as a result of increased intensity of radiation from the mulch. It has also been found that vitamin C in tomatoes increases rapidly with increase in soil moisture until enough water is present for the fruits to approach 95 per cent moisture when fully ripe (Hoffman *et al.*, 1938). Thus it seems reasonable to expect

that under dry conditions mulching might improve the vitamin content of the fruit by conserving soil moisture.

On pests and diseases

Much of the work on mulches in relation to tomato pests and diseases has been concerned with glasshouse problems and practice, and will therefore be discussed under the heading *Glasshouse Tomatoes*. Only work that has primarily been carried out on field crops will be discussed here.

Some interesting results were obtained at the Florida Agricultural Experiment Station on tomatoes grown on root-knot infested soil (Florida, 1938-51). In a preliminary series of pot experiments tomatoes were (1) heavily mulched with various decaying materials including dried grass, crotalaria stems, leaf mould and water hyacinths, (2) watered with an infusion made by soaking some of these mulch materials in water for several days, and (3) watered with tap water as controls ; 24 plants were used in each treatment. All the control plants died without flowering and the roots were heavily damaged by root-knot. All but two of the mulched plants produced fruit and were very little damaged by root-knot. All but four of the plants watered with infusion produced fruit and a light infestation of root-knot was recorded (Florida, 1942 ; Watson, 1944). In another pot experiment mulched tomatoes made good growth and bore a good crop whereas the controls again died before the fruiting stage, but in this case the roots of all the mulched plants were as badly knotted as those of the unmulched (Florida, 1943). In a field experiment with various materials all the mulched plants made better growth than the controls, the deeper the layer the better the results, while the type of mulch material made very little difference provided it decayed quickly and covered the ground well (Florida, 1944). Later tests showed that a deep mulch of forest leaves resulted in higher yields than a mulch of miscellaneous plant material or than no mulch, the figures being 10,075 lb., 6,150 lb. and 3,975 lb. per acre respectively. Examination of the roots, however, showed that root-knot infestation was heaviest under the forest leaves and lowest under the miscellaneous material (Florida, 1950). These results, and others with a wide range of crops, indicate that mulching is ineffective for root-knot control but that it frequently greatly improves growth and yield of plants grown on nematode-infested soil by improving soil conditions.

Recent work at the Rehovot Agricultural Experiment Station (Avidov, 1956) has shown how infestations of white fly (*Bemisia tabaci*), which may be so serious on tomato seedbeds in summer, can be practically eliminated by mulching with sawdust. The repellent effect was not due to the odour of the resins in the sawdust but to the higher temperature of the air just above the mulch. At the hottest hour of the day the surface temperature

was 6° C. higher above the mulch than above bare soil and exceeded 46° C., the temperature lethal to the adults. Even on mulched seedbeds, however, there was a danger of attack when the seedlings had grown beyond the height (10 cm.) at which the reflected heat was intolerable to the fly. A peat mulch did not have the same beneficial effect.

Other information on the effect of mulching on tomato pests is limited to the passing observations that green cicada (*Chlorita signata*) attack was less severe on plants mulched with straw + cottonseed waste in Israel (Griss, 1949), and that cutworms caused considerably more damage under a paper mulch in each of two seasons in South Africa (Anon., 1927).

With regard to disease, the most consistently favourable effect of mulching appears to be in the control of blossom end rot. This is a physiological disorder associated with disturbed water relations within the plant. There is general conformity of opinion, indeed it has become textbook information, that mulching with straw, grass or other litter will reduce the amount of blossom end rot by conserving moisture during dry periods and regulating the supply (Jackson, 1954 ; King, 1956 ; Lachman, 1946 ; Shoemaker, 1947 ; Talbert and Hibbard, 1943 ; Wager, 1946 ; Weaver and Bruner, 1927). In the case of the outdoor crop this opinion appears to be based on field observations rather than on any critical work, but experimental work on glasshouse tomatoes provides supporting evidence. Aluminium foil mulch has also been reported to reduce incidence of the rot considerably (Wall, 1950). Paper mulched plants, on the other hand, produced significantly more fruits with blossom end and soft rots than unmulched plants in two consecutive seasons, in spite of the fact that soil moisture was consistently higher under the paper (McCubbin and Westover, 1933). The reason for this is not clear, but the authors suggest that it might have been due to the higher state of vigour of the mulched plants during the early part of the season (see also *Sweet Peppers and Eggplants*).

In the case of soilborne fungus diseases, mulching can help to reduce infection by preventing splashing and by keeping the fruit off the ground, particularly in the case of unstaked tomatoes (Gilbert, 1956 ; Jackson, 1954 ; U.S. Dep. Agric. Office of Information, 1945). Thus a straw or peat mulch is said to reduce the incidence of buckeye rot (*Phytophthora* spp.) which is largely confined to fruits in contact with the soil (Doolittle, 1948). In a very wet season in Germany, when fruit which fell on the soil became infected with *Phytophthora infestans*, paper mulching helped to reduce the loss from blight (Hatt, 1926).

The development of *Cladosporium* leaf mould, which is favoured by conditions of high humidity, was greatly retarded by mulches of compost, hay, straw, etc., in field trials in Israel (Aharonovitch and Ulman, 1947 ; Griss, 1949) ; it was thought that this may have been due to the fact that less irrigation was needed on the

mulched plots so the foliage remained drier. In one of these trials (Griss, 1949) bacterial blight (*Bacterium vesicatorium*) infection of the fruit was also less severe on the mulched, less heavily irrigated plots.

In some papers on tomato mulching the effects on disease in general are mentioned without specific reference to the causal agent. For instance, Werner (1933) in Nebraska found that strawing reduced the number of rotted fruits, whereas paper mulching increased it in dryland culture and reduced it on irrigated land. Mulches of old hay, fresh hay, salt hay or excelsior in New Jersey made little difference to the prevalence of disease except in one year when salt hay increased the amount of rotten fruit (New Jersey, 1896, 1897, 1899). Rosa (1923) points out that strawing, by delaying maturity, may increase the danger of loss from disease ; he states that in a wet season all the mulched plants were killed by disease which appeared after the early crop had been harvested from the unmulched plots. Paper mulched plants, on the other hand, did not suffer in a very wet summer when the controls became diseased and unsaleable by mid-September (Mann, 1931). Whether this was due to earlier maturity or to lower air humidity over the paper is not clear. In a test at Weihenstephan (Weihenstephan, 1929) there was also a decrease in the number of diseased fruits on paper-mulched plots, especially when the plants were unstaked.

Time of Mulching

At one time it was considered that mulches should be applied early in the season while the soil was still wet from the winter rains in order to conserve as much moisture as possible. At the end of the last century Halsted (New Jersey, 1899) concluded, from an experiment on mulching tomatoes with salt hay, that the value of mulch undoubtedly depends on earliness of application and the amount of moisture in the soil at the time. He considers that, within limits, the earlier the mulch is applied the better will be the results obtained. This opinion, however, appears to be purely conjectural for no comparative experiments on time of mulching are reported. A few years later Emerson (1903) obtained variable results from mulching tomatoes with wheat straw, and attributed his failures to the effects of too early mulching which kept the soil too cool and delayed the early growth of the plants. He advises that mulching should be delayed until the soil has warmed up in the spring.

Later experience suggests that Emerson's advice was right. Nowadays commercial growers generally straw their tomatoes when they are 12-15 inches high (Shoemaker, 1947). The most suitable time for mulching will naturally depend on the nature of the soil, as heavy soils will warm up more slowly in the spring and will tend to retain moisture better than light soils, and therefore should be

covered later. A recent circular from Missouri (Talbert and Hibbard, 1943) recommends that on soils inclined to be wet or heavy mulch should not be applied until about 1 July, that is about a month after planting. Experimental work in Pennsylvania (Isenberg and Odland, 1950) confirms that this practice of delayed mulching is sound. Tomatoes planted on 9 June were mulched with shredded corn fodder either immediately after planting, after one cultivation, or after two cultivations (27 July). The soil type is unfortunately not specified. The weather during June and early July was extremely hot, but even so significantly higher early and total yields were obtained as a result of delaying the application of mulch. The mean total yields were as follows : cultivation only 389·6 lb., mulch immediately after planting 464·7 lb., mulch after one cultivation 539·7 lb., mulch after two cultivations 587·3 lb. It is considered that the benefits of delaying mulching until the soil has been cultivated once or twice after planting are possibly due to better weed control and warmer soil.

GLASSHOUSE TOMATOES

Benefits of mulching

In England " the practice of covering the soil with a layer of loose organic material such as strawy horse manure is common in many horticultural establishments, and has been adopted by tomato growers ever since this crop was grown commercially " (Bewley, 1950). In order to determine the value of this practice a series of experiments was carried out in the glasshouses at Cheshunt in 1920-22 on the variety Ailsa Craig (Cheshunt, 1921, 1922, 1923). A comparison was made between clean straw, strawy horse manure and no mulch. The three years' results showed that mulching had very little effect on the weight of crop produced, but that strawing resulted in plants with cleaner growth and less " stripe " disease than the other treatments. Moreover, less water was needed on the mulched plots because evaporation was reduced. Reviewing these results later, Bewley (1950) concludes that where the land is reasonably level and retentive of water, and the plants are healthy, little advantage is to be gained from mulching, indeed it may often be a waste of money, but that it is certainly advisable on sloping or very light land to retain moisture. There now appears to be a fairly general consensus of opinion in Great Britain (Minist. Agric., London, 1950 ; and others) that mulching may be desirable on certain soils (1) to conserve moisture, (2) to prevent the packing and leaching effects of heavy watering on an exposed surface, (3) to stimulate growth by a constant small supply of nutrients (where manure is used), and (4) in the treatment of certain diseases [see **Mulching for pest and disease control**].

Recent work at the West of Scotland Agricultural College suggests a further use of mulching in glasshouses, namely in the

treatment of induced magnesium deficiency (Hunter, 1946). Sand culture experiments showed that absorption of Mg was most restricted and chlorosis most severe when the nutrient solution was relatively concentrated and the ratio of K to Mg in it was high. Preliminary results obtained in the greenhouse by early mulching with farmyard manure or peat suggested that an encouragement of secondary root production by such means may go far to offset the conditions under which induced Mg deficiency appears.

In parts of British Columbia toxic soil conditions have developed in tomato houses owing to the continued application of excessive amounts of fertilizer and to low pH. The tomato crops have been unsatisfactory under these conditions, but considerable benefit has been derived from either leaching or autumn mulching with 3 inches of sawdust (British Columbia, 1955).

Mulches are also sometimes applied to pot-grown tomatoes for the purpose of reducing evaporation. Loads (1952) recommends that pot tomatoes should be mulched with partially rotted manure in the same way as border plants, and suggests that if no manure is available lawn mowings may be used for the purpose although they do not have the additional advantage of providing food. Even plants grown by soilless culture methods have been mulched experimentally, and Saunby (1953) considers that some system of mulching is particularly beneficial for tomatoes as the rooting medium dries out rapidly after the plants have been defoliated. He suggests that pots or small containers of sand may be mulched with a layer of clean moss, preferably sterilized, to prevent evaporation, and that sand beds can be covered or partially covered with scrim or hessian. Not only does the covering conserve moisture, but the plants are said to benefit by being grown in a cooler medium.

In the United States the situation is similar to that in Great Britain in that mulching of glasshouse tomatoes is an old established practice in spite of the fact that it has not generally increased yields. Thirty years ago mulches of manure and other organic materials were commonly used on the spring and sometimes on the autumn crops of glasshouse tomatoes because it was thought that they would conserve moisture, reduce the labour of watering and cultivation, prevent weed growth, supply plant foods, keep the soil cool in hot weather, and prevent packing of the soil by trampling while it was wet (Beattie, 1924 ; Hoffman, 1929a, 1932a).

About this time Hoffman began an extensive series of experiments in Ohio in which he showed that mulches were not so beneficial as was previously supposed. In the first experiment with spring tomatoes on freshly sterilized soil, well-rotted horse manure, fresh strawy horse manure, fresh horse manure in wood shavings, steamed garbage, dried tobacco stems or chopped corn stover (very low in nitrogen) were applied six weeks after planting. Within two weeks signs of nitrogen deficiency appeared on all the mulched plants, i.e. lighter green foliage, retarded growth and slower opening of

blossoms. Fruit ripening was delayed and the fruits matured much more irregularly than on the control plots. The unmulched plots produced more fruits per plant than any of the mulched plots and a greater total weight of fruit than the plots mulched with well-rotted manure, fresh strawy manure or steamed garbage. Even with the other three materials, which produced a slightly greater total weight of fruit, owing to larger size, than the controls, the increase did not justify the time and expense of mulching. The plots mulched with fresh strawy manure were lowest in both number and weight of fruit because the material contained the largest supply of soluble carbohydrates and so caused the greatest nitrogen deficiency. In an experiment on the autumn crop, well-rotted cow manure was applied after the first fruits had set. The mulch reduced the total number and weight of fruit and the size and percentage of grade 1 fruit, increased the number of culls and delayed ripening. The loss amounted to 17·3 per cent or nearly $\frac{1}{2}$ lb. fruit per plant. The effect was again attributed to induced nitrogen deficiency. Moderate weekly dressings of sulphate of ammonia helped to overcome the trouble but were not sufficient to restore the balance completely (Hoffman, 1929a, b, c, 1930, 1932a). In a further test with cattle manure on unsterilized and sterilized soil, mulching proved harmful in the former case but beneficial in the latter. Although fewer fruits were set per plant on the mulched sterilized plots than on the unmulched they became larger and the total weight was increased by 12·6 per cent. It is concluded that the possible benefit of mulching on freshly sterilized soil is due to the reinoculating effect of the manure (Hoffman, 1932a and b). Another factor probably involved, but not mentioned by Hoffman, is that the accumulation of nitrogen which occurs in freshly sterilized soil may have been sufficient to offset the tie-up of nitrogen resulting from the decomposition of the mulch.

In addition to showing that mulching with materials rich in soluble carbohydrates may have a positively harmful effect, Hoffman also found in these tests that the advantages previously claimed for mulching were largely unfounded. He found, for instance, that as much water was needed on the mulched as on the control plots. It should be noted that this is contrary to the results obtained in England (Cheshunt, 1923). Soil temperatures were only reduced by $1\frac{1}{2}$-2° F. by mulching. Mulching did prevent the formation of a surface crust but did not make the soil any easier to work. The amount of soluble fertilizer elements left in the manure when it was brought into the greenhouse was small. Weeds were suppressed to some extent but the cost of mulching proved greater than the cost of cultivation.

Thus it was shown that under normal glasshouse conditions mulching was valueless and, owing to the tie-up of nitrogen, might even be detrimental. It is pointed out, however, that under certain special conditions mulching may be of distinct value, and Hoffman

(1932a) recommends it in the following cases : (1) On extremely rich soil with a large supply of available nitrates : mulches containing soluble carbohydrates may be needed with early tomatoes to reduce the nitrate supply and thus improve fruit set, although the addition of nitrogen may be required later to bring the crop to full maturity. (2) On sloping land : mulches may be needed to retain water and assist penetration in the higher parts. (3) On heavy soils : mulching will help to keep the surface moist and prevent cracking which may cause serious root injury. (4) On freshly sterilized soil : mulching with manure helps to reinoculate the soil rapidly with micro-organisms.

In view of the value of mulching on sloping or heavy ground, work was continued at the Ohio State University with the aim of finding a mulch material that did not result in nitrogen deficiency (Marion, 1933). Clover chaff was selected for trial as it contains a high proportion of nitrogen compared with carbohydrates, and was available in large quantities at a reasonable price. Analyses showed that clover chaff has a nitrogen:carbohydrate ratio of 1:16 whereas that of horse manure is 1:40. With both spring and autumn crops of tomatoes in the greenhouse, clover chaff applied at the rate of 6-8 tons per acre resulted in the production of good yields of high quality fruit. The crops showed no evidence of nitrogen starvation. [Results of controlled experiments are not given.] The amount of blossom end rot was said to be greatly reduced by the use of this mulch provided it was applied after the plants were waist to shoulder high and had developed a deep, wide-spreading root system. Where soluble salts were present in the soil in any quantity the mulch was found to be of special benefit as it absorbed the salts and prevented their accumulation at the surface of the soil in injurious concentrations. Marion reports that practically all growers who had tried clover chaff as a mulch were very much pleased with the results, and concluded that it was the best and cheapest mulching material available at that time. Hoffman (1936a and b, 1938) also confirms that mulches with a high nitrogen:carbohydrate ratio, such as clover chaff, low grade alfalfa hay or soya bean straw, make satisfactory mulches and do not deplete soil nitrogen during decomposition. Much of their own nitrogen, moreover, is finally released to the plants, but not until late in the life of the crop.

These findings appeared to provide the solution to the problem—materials rich in nitrogen could be used to retain water on sloping land and to prevent cracking on heavy soil without causing the nitrogen deficiency which had generally been the accompaniment of straw or manure mulching. Further experiments, however, showed how difficult it is to reduce the problems of mulching to such simple terms. In tests carried out over several years in commercial glasshouses a mulch of wheat straw was found to give as good yields as a mulch of mixed legume hay (Hoffman *et al.*, 1945, 1946 ; Hoffman, 1947). The mulches, applied at 8 tons per

acre, were tested on both spring and autumn crops, and on fine sand and heavy clay, with and without lime. Averaging the results obtained on limed and unlimed soils, there was no significant difference in number or weight of fruit between the nitrogenous and non-nitrogenous mulch materials. On the heavy clay soil, however, the straw mulched plants yielded considerably more where no lime had been applied, and the plants mulched with legume hay yielded better on the limed plots ; the difference in each case amounted to about 1 lb. fruit per plant. No explanation is given for the fact that straw gave as good average results as the highly nitrogenous legume hay. It may have been due to the fact that the soil was initially rich in nitrogen. These results, however, in cluding the differential effects of liming, emphasize how profoundly the performance of a given mulch material is affected by soil conditions.

In recent years the possibility of using mulches for an entirely different purpose, namely for increasing the radiation of light, has been studied at Geisenheim in Germany. Weger (1950a, 1951a, 1952) investigated the effect of a light-coloured soil cover on the growth and cropping of glasshouse tomatoes. In the spring of 1949 he covered part of the soil with light kaolin sand to a depth of 1 cm., the rest of the soil which was left uncovered being a dark brown. The sand was practically sterile, thus eliminating the possibility of the results being affected by the presence of mineral nutrients. The soil temperature under the sand and air temperature and relative humidity over it were slightly lower than those on the uncovered plot. The radiation, however, at a height of 70 cm. was twice as strong over the sand as over the dark soil, the measurements on cloudless days being 3,600-4,100 Lux from light sand and 1,700-1,900 Lux from dark soil, and on cloudy days 400 Lux from the sand and 200 Lux from the soil. The mulch had little effect on the growth of the plants or on the time of ripening but the total yield was considerably increased. With bush tomatoes yields were higher throughout the entire season on the covered plots, the final increase being 23 per cent. With staked tomatoes the effect was only noticeable after the first month of harvest and the final increase was 8 per cent. This difference is explained by the fact that the soil was shaded less by the bush than by the staked plants so the radiation effect was greater. As temperature differences were so slight, the benefit from the mulch is attributed to the greater intensity of radiation, the more favourable spectral composition and possibly the higher soil moisture.

Mulching for pest and disease control

The purpose for which mulching is probably used to greatest advantage in glasshouse nurseries in Great Britain is for the encouragement of new root production in tomatoes that have become infected with root rot and certain other diseases. The discovery that a peat mulch could be used in this way to save an

infected crop was made at Cheshunt in 1934 (Bewley, 1950 ; Cheshunt, 1936) when tomatoes grown in unsterilized soil began to wilt and collapse when already laden with fruit. Examination showed the presence of common root rot, caused by various fungi and bacteria including *Colletotrichum atramentarium, Fusarium* sp., etc., in a fairly advanced condition. In an attempt to save the plants, atmospheric humidity was increased by shading the glass, closing the ventilators and giving frequent overhead damping, and a 1½-inch layer of sphagnum peat moss was spread over the surface of the soil and kept in a moist condition. Another house with the same soil conditions showed no signs of wilting and was used as a control. Five days after application of the mulch new roots emerged from the stems and began to enter the moist peat, and within 14 days root growth in the mulch layer had advanced sufficiently to maintain the plants in a turgid condition when overhead damping was reduced and full ventilation given. Light dressings of an organic fertilizer were applied on top of the peat and the plants remained healthy until the end of the season. The mulched house produced a crop of 38 tons per acre whereas the control yielded only 32 tons. The yield during the early part of the season was also higher than in the control and the quality of fruit was exceptionally good. Similar treatment was also given in a house where severe eelworm attack had developed in addition to root rots, and the roots were so badly diseased that without treatment the plants must have died. In this case also root growth became active in the peat layer and the plants yielded an average crop of 42·38 tons per acre. Since then the practice of mulching root rot infected plants with moist peat has been followed extensively by growers with remarkable results. It is also recommended as a treatment for *Verticillium* wilt (Allerton, 1954).

Glasshouse experiments at Cheshunt also showed that tomatoes mulched with clean straw developed less " stripe " disease than those mulched with dung or unmulched (Cheshunt, 1921, 1922, 1923). Bewley (1950) later observed that a cow dung mulch encourages the disease. The reasons for this are not discussed. Earlier work, however, had indicated that susceptibility to " stripe " appeared to depend on the vigour of the plants in the early stages of growth, and that excessive nitrogen or too little potash rendered the plants more susceptible. Thus it seems possible that the beneficial effect of a straw mulch may be due to its retarding effect on early growth resulting from a tie-up of nitrogen in the soil and an increase in potash content.

As in the case of field tomatoes, a mulch of clean straw or peat will help to reduce infection by soilborne diseases by preventing splashing and contact of the fruit with the soil. It has thus been recommended as a preventive measure against buckeye rot (Loads, 1952) and stem rot caused by *Phytophthora parasitica* (Williams and Sheard, 1944).

The opinion, widely held by growers of field tomatoes, that mulching will help to prevent the development of blossom end rot by conserving moisture has been confirmed to some extent by glasshouse experiments. For instance, in a 3-year trial at Cheshunt mulching with straw or dung slightly reduced the incidence of the disorder (Cheshunt, 1921, 1922, 1923). And in tests at the Ohio State University the use of a clover chaff mulch greatly reduced the amount of blossom end rot provided it was not applied until the plants were waist to shoulder high (Marion, 1933). It was recommended that in the early stages the plants should be grown rather cool and dry with frequent shallow cultivations in order to develop a deep, widespreading root system. After the mulch has been applied a mass of secondary roots will be formed in the surface layer and the plants will thus be enabled to obtain sufficient moisture during hot weather.

Straw mulching in tomato houses can also be of use in reducing the population of red spider mites (*Tetranychus telarius*). In the course of investigations at Cheshunt it was noticed that a straw mulch lying under the plants contained large numbers of hibernating mites in October and November (Speyer, 1927). The presence of the straw appeared, at any rate to some degree, to prevent the mites from getting into the ridge prior to hibernation. Experiments were therefore started on the possibility of using straw to trap the mites and so reduce the number hibernating in inaccessible cracks in the house (Orchard, 1928). It was calculated that in a heated house about 65,000 mites were trapped per cwt. straw. The number found in the straw residue from a dung mulch was smaller and, as dung mulch is more difficult to sweep up after the crop has been removed, the use of clean straw was considered preferable. On the basis of these results it was recommended that straw should be spread over the soil before the end of August at the rate of $1\frac{1}{2}$ bundles to a house 200 feet long and 12 feet wide, and that after removal of the crop every particle of straw should be swept up and burnt. It appears, however, that such scrupulous care in removal of the straw is not essential, for when bundles of infested straw were buried in the soil at the end of October 75 per cent of the mites died or were lost in the soil within 10 weeks, and after a further 18 weeks no live mites remained. Tests showed, moreover, that no live mites could survive until spring in the soil of glasshouses, so small pieces of straw remaining in the house would not serve as sources of infestation provided they were dug into the soil. Reduction in the number of hibernating red spider is thus an important point in favour of the use of straw mulches on the summer crop of glasshouse tomatoes.

Types of mulch material

The mulch material most widely used by glasshouse growers in England is probably strawy stable manure, as this is thought to

provide a continuous small supply of nutrients as well as conserving moisture. How far this is true is uncertain and would naturally depend on the treatment of the manure, but American work suggests that most of the soluble nutrients are leached out of the manure before it is brought into the glasshouse (Hoffman, 1932a). It is generally recommended that the manure should be prepared before being brought into the house, to allow excess ammonia to escape. Saltmarsh (1945) advises the use of half-made stable manure to which some clean straw has been added to give greater bulk, and says that the material should be spread out in the open and turned 2 or 3 times to cool it and stop fermentation. After the mulch has been applied some top ventilation should be left on at night to prevent possible leaf scorch from ammonia fumes. Loads (1952) also recommends the use of partially rotted farmyard or stable manure, which should not be so decayed that it will not last through the season, but which should have been stacked for three months and turned several times. He advises shaking out the long straw, however, as this is untidy and difficult to manage in the house. Cow manure, on the other hand he considers to be unsuitable for use on wet soil as it clogs the surface. Bewley (1950) also warns against cow manure on the grounds that its physical condition is unsuitable and it encourages the development of " streak " disease.

Other materials that are sometimes used on glasshouse tomatoes in England include clean straw, peat moss and spent hops. It is considered by some authorities (Minist. Agric., London, 1950) that these materials are usually preferable to horse manure, except where the soil has not been adequately manured before planting. Bewley (1950) also recommends them in preference to manure in districts where leaf mould is severe, as they are dry and thus tend to reduce the atmospheric humidity. If spent hops are used they should be applied in a layer sufficiently thick for the surface of the mulch to remain dry, for if they are left on the ground in a thin broken layer they will become wet through and botrytis will grow on them readily (Minist. Agric., London, 1950). For mulching diseased plants to encourage new root production a good quality peat should be used. Sphagnum is considered better than sedge peat, and coarse peat better than fine dusty material ; very acid peat is harmful because it contains compounds injurious to tomato roots (Bewley, 1950).

In a Danish trial Dano-fertilizer, i.e. town refuse prepared by a special method, has proved a suitable mulch material for glasshouse tomatoes as it does not contain ammonia and so will not scorch the foliage (Pedersen, 1939).

In the United States, where nitrogen deficiency induced by mulching appears to have been a more serious problem than in England, more attention has been paid to the composition of mulch materials. A trial with various materials in Ohio (Hoffman, 1932a) showed that mulches containing the largest proportion of soluble

carbohydrates caused the most severe nitrogen deficiency. Of the six materials tested, fresh strawy horse manure was the most injurious. Fresh horse manure in wood shavings caused only temporary nitrogen deficiency because the carbohydrates in the wood were much less soluble than those in straw and decomposition was slow. The plants soon recovered and matured a crop even larger than that of the controls, suggesting that the plants were able to use the mulch as a source of fertility. Dried tobacco stems and corn stover mulches, providing cellulose material very low in nitrogen, resulted in low fruit set but exceptionally large fruit ; this suggested that bacteria acted so slowly on these materials that nitrogen deficiency never became a seriously limiting factor. With rotted horse manure nitrogen deficiency was only temporary, while with steamed garbage (town refuse) the nitrifying action was slow and the deficiency was not serious. Materials with a high nitrogen: carbohydrate ratio such as clover chaff, alfalfa hay and soya bean straw were found not to deplete soil nitrogen during decomposition (Hoffman, 1936a and b, 1938 ; Marion, 1933). Recent American work has shown that lignin prepared by saccharification of corncobs gives better results than sawdust as a mulch for glasshouse tomatoes (Wang, 1953).

For certain purposes inert types of mulch materials have been used experimentally. In the soilless culture of tomatoes, for instance, sterilized moss is recommended for preventing evaporation from the sand in small containers, and scrim or hessian for covering sand beds (Saunby, 1953). A cover of light coloured kaolin sand has been used successfully to increase the intensity of radiation in tomato houses (Weger, 1950a, 1951a, 1952).

Time of mulching

As a mulch will prevent the soil from warming up in the spring, it should not be applied too early. The Ministry of Agriculture (1950) warns against mulching before the middle of May. Bewley (1950) records the experience of a grower who applied a straw mulch before planting with the result that growth was seriously checked owing to the low soil temperature. It is common practice in some areas to apply stable manure or straw just as the fruits start to colour (Univ. Leeds, 1934), but Loads (1952) recommends that manure mulch should not be applied before the first truss has been gathered to avoid dirtying the lowest fruits during the process. Moreover, at this time the lowest leaves will be turning yellow and can be removed to allow free circulation of air, the roots may have become partly exposed and require covering, and the plants will have reached a stage when they need extra nourishment. If a straw mulch is used for the purpose of trapping hibernating red spider mites, it should be applied before the end of August (Orchard, 1928).

Depth of mulching

Opinions differ somewhat on this point. According to Saltmarsh (1945) many growers spread their manure mulch about 4 inches deep. Loads (1952) recommends a 3-inch layer of manure, and Bewley (1950) says that the depth need not exceed 2 inches and that two light mulchings at an interval of about six weeks are better than one heavy application. When peat is used as a surface rooting medium, a depth of $1\frac{1}{2}$ inches (10 tons per acre) is recommended (Cheshunt, 1936 ; Minist. Agric., London, 1950).

CONCLUSIONS

Field Tomatoes

Mulching field tomatoes with straw or hay is a fairly common commercial practice in districts where shortage of water is a problem. Provided soil temperatures are high enough the practice will generally increase yields, but it may retard maturity. Nitrogen deficiency may result, especially on poor soils. By conserving moisture mulching will reduce the amount of blossom end rot, and by keeping the fruit off the soil it will help to prevent infection by soilborne diseases. The results of one trial indicate that mulches may increase the carotene and mineral contents of tomato fruits. Straw and other plant residues which tend to reduce soil temperatures should not be applied until the soil has warmed up.

Sawdust mulches may improve yield and quality of fruit, provided sufficient nitrogen is applied and the sawdust is not mixed too rapidly with the soil.

Results with peat and woodwool have been variable and it is not possible to draw definite conclusions on their value from the evidence available.

Asphalt paper, which tends to increase and stabilize soil temperatures, has often resulted in more rapid growth, higher yields and earlier ripening of field tomatoes, but its effect will depend on soil and weather conditions and variety. It is most likely to be beneficial on heavy or medium soils which have a good supply of moisture.

Black polyethylene plastic, which has the same forcing properties as asphalt paper but is cheaper and less fragile, has given very promising results in a preliminary test. By preventing ground spotting it may be used to replace staking. The life of the plastic is estimated at 4 years, and in a single season the increased returns paid for the material several times over.

Glasshouse Tomatoes

Mulching glasshouse tomatoes with strawy manure is a common practice in England and America, but it has not generally resulted in increased yields. It may produce nitrogen deficiency with a

resultant reduction in yields. Opinions differ on the extent to which manure mulches provide nutrients and conserve moisture.

In England mulches of straw, peat or spent hops have been recommended as satisfactory alternatives to dung. In America highly nitrogenous materials, such as mixed legume hay, are recommended as they do not cause nitrogen deficiency.

In special cases mulching in glasshouses is likely to prove worth while, namely : (1) on sloping or very light land for the retention of water, (2) on very heavy soil to prevent cracking, (3) on soils exceptionally high in nitrogen to reduce the nitrate supply early in the season, (4) on freshly sterilized soil to assist rapid reinoculation with bacteria, (5) in the treatment or prevention of certain diseases, (6) in the treatment of induced Mg deficiency, and (7) in the treatment of toxic conditions due to high salt concentrations in the soil.

One of the most valuable uses of mulching in glasshouse work is for the encouragement of new root production on plants infected with root diseases or root-knot eelworm. For this purpose a thin layer of moist peat is used.

The possibility has been demonstrated of increasing the intensity of light radiation, with a consequent increase in yields, by the use of light kaolin sand.

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